

Technology Needs for U.S. Unconventional Gas Development



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Acronym List

3-D	Three Dimensional	MWX	Multi-Well Experiments
BLM	U.S. Bureau of Land Management	NETL	U.S. National Energy Technology Laboratory
BMP	Best Management Practices	NMT	New Mexico Institute of Mining and Technology
BPJ	Best Professional Judgment	NPC	National Petroleum Council
CBM	Coalbed Methane	PA	Pennsylvania
CBNG	Coalbed Natural Gas Alliance	PGC	Potential Gas Committee
CO	Colorado	POD	Plan of Development (BLM)
DOE	U.S. Department of Energy	R&D	Research and Development
E&P	Exploration and Production	RD&D	Research, Development and Demonstration
e.g.	for example	RMOTC	Rocky Mountain Oilfield Test Center
EA	Environmental Assessment	RMP	Risk Management Plan
EIA	Energy Information Agency	RPSEA	Research Partnership to Secure Energy for America
EIS	Environmental Impact Statement	SFE	Staged Field Experiments
GIS	Geographic Information System	tcf	Trillion cubic feet
GRI	Gas Research Institute	TX	Texas
GTI	Gas Technology Institute	U.S.	United States
LNG	Liquefied Natural Gas	UGRP	Unconventional Gas Research Program
MHD	Microhole Drilling	USGS	United States Geological Survey
MMS	Mineral Management Services		





Executive Summary

The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) sponsored a series of three workshops to obtain input on current industry research and development needs for unconventional gas. In order to encourage participation from stakeholders working in various regions of unconventional gas resources in the continental United States, workshops were held in Houston, TX, Golden, CO and Pittsburgh, PA. To promote an informal discussion atmosphere, attendance was limited to approximately 25 people per session.

Unconventional gas is a technology sensitive gas resource. Increases in production will be directly related to the application of new techniques and procedures by the gas producing industry. The development of the coalbed methane resource is an excellent example of this approach. Throughout the workshops and other discussions with industry the goal was to determine the optimum technological approaches to increase gas production from coalbed methane, gas shales and tight gas sands (unconventional gas resources).

Most participants indicated that a robust research program will be required to achieve significant production increases from unconventional gas. While exact figures were not possible to determine, it was felt that past programs of \$50 million per year are representative of the minimum reasonable level of effort that needs to be applied for the future. Three research areas were identified.

Research Area I - Development and Characterization of New Resources - This research area involves activities that will result in the development of resources that are not the major focus of current E&P activity. These activities are longer-term research elements, but they have the potential for dramatic increases in reserves and production if significant new resources are identified.

Research Area II - Reduced Development Costs of Existing Resources - This focus area includes activities that will lower the cost of developing or facilitate the development of unconventional gas resources that are currently known and under some degree of development. The focus here is generally on well drilling and completion technologies, formation evaluation techniques and databases. These activities have the potential to impact the U.S. gas supply in the near to mid term.

Research Area III - Crosscutting Topics - This research area involves activities with significant potential to enhance unconventional gas production, but that transcend the specific technical topics associated with the first two areas. This category includes environmental issues that cut across several technical disciplines, technology dissemination projects, and E&P personnel training to apply the new technologies.

An important component of the R&D effort is the need for a strong field-based research program. It is clear from past successes in unconventional gas that breakthrough insights have been the result of well planned field experiments to test new theories and obtain petrophysical data that is otherwise unavailable to the producing industry. Field projects provide an indispensable laboratory for testing and





improving new and evolving engineering tools to support development of unconventional resources. A carefully planned field test allows these new tools to be thoroughly tested in the environment of their application (specific unconventional gas formations).

Successful in the past, the cost and risk of field based research programs have limited their undertaking in recent years.

In the past, field-based experiments have also provided a basis for effective technology transfer efforts. Research wells in unconventional gas formations have provided heretofore-unavailable information and insights that were then disseminated to develop industry interest in planning and executing future programs.

An effective technology development effort must address both near- and long-term issues. Development of an additional 4 tcf per year production by 2025 (NPC, 2003) from unconventional resources is a significant task. Additional production capacity must come from a better understanding of how to effectively produce gas from well-characterized resources as well as from resources that have not been fully characterized (e.g., basin-centered gas and deeper reservoirs). Research aimed at this last category of unconventional resources is an important program component. Due to the long lead time needed to cost effectively bring unconventional resources to market, these efforts must be balanced in the early years by further development of known unconventional resources.

Crucial to the success of any unconventional gas technology development effort is industry participation in all stages of research from concept development to field demonstrations. Research must remain focused on industry needs, and industry experts must be involved in the monitoring of progress through a regular review process. Industry partners must be participants in field demonstrations and new technology testing activities. In addition, only cost sharing by industry participants will make it possible to embark on many otherwise cost-prohibitive field-based projects. This involvement assures relevancy and provides credibility, making effective technology transfer much easier.

New technology played a major role in increasing non-conventional gas production from 1.0 to 4.8 Tcf/year during the decade of the 1990's and helped provide for a reliable, secure and modestly priced supply of natural gas to U.S. gas consumers. New technology can have a similar impact over the next decade and provide multiple benefits to the general public including:

- Less dependence on imported energy as domestic resources are made available,
- A cleaner environment as gas replaces other fuels,
- Reduced consumer costs that follow from an expanded gas supply, and
- Positive impact on local and national economies as new jobs are created in the exploration and production industry and job losses are avoided by the dampening of energy price rises.





New drilling technologies are allowing wells to be drilled more rapidly in many of the unconventional resources. A significant infrastructure is already in place to produce and transport the gas to market, and industry knows where many of the resources are located. Unconventional gas resources are expected to contribute large volumes of gas to supply the nation's energy demand, but meeting this expectation will require technology enhancements.

Recommendation

Based on workshop input and analyses of past workshops by the National Petroleum Council and New Mexico Tech, unconventional gas R&D should focus on three primary technology areas:

- Research Area I - Technologies that can help industry understand and characterize the unexplored unconventional gas resource in geologic basins in the United States. This area will target currently non-producing basins and formations. The technology areas of primary importance will be geological and geophysical with deliverables focusing on the resource characterization topic. A simply stated goal is: to find new gas.
- Research Area II – Technologies to enhance production in existing areas. This focus area will target unconventional gas areas of near-term or current activity. The technology areas of primary importance fall within well construction procedures and techniques (drilling and completion of unconventional gas wells), reservoir characterization and modeling and production issues such as produced water.
- Research Area III - Crosscutting efforts such as environmental technology development, E&P industry personnel training, and technology dissemination. These efforts must be closely integrated with activities in Focus Areas I and II to assure acceptance and use of the new technologies.

The following table summarizes major components of each of the three focus areas. Each of these is discussed in further detail after the table.

Research Area I. Development and Characterization of New Resources	<ul style="list-style-type: none"> • Resource Assessment • Basin-Scale Petroleum Systems Studies • Field-Based Testing
Research Area II. Reduced Development Costs of Existing Resources	<ul style="list-style-type: none"> • Data Access • Reservoir Characterization • Production Prediction and Optimization • Advanced Well Construction
Research Area III. Crosscutting Topics	<ul style="list-style-type: none"> • Technology Transfer • Environmental and Land Access • Manpower/Training • Basic Research

Research Area I - Development and Characterization of New Resources - A key to past success in unconventional gas production research has been a significant field program, including the drilling of “fit for purpose” research wells to address the





petrophysical and engineering variables associated with unconventional gas. It is recommended that field studies be planned and implemented in each of the unconventional geologic basins important to future gas production. Specific steps for each basin should include:

- Prioritize all geologic basins using criteria developed through a gas potential, industry activity and prioritization study.
- Select high potential basins and design detailed resource characterization wells to acquire needed data.
- Utilize research wells to conduct field tests of promising technology for the target basin and further program product development where appropriate.
- Define deliverables for each basin that include, at a minimum, a basin scale petroleum study addressing unconventional gas, and a resource estimate of both gas-in-place and economically recoverable gas. The data and studies need to be formatted for wide dissemination and easy access.
- Maintain the well test site(s) for future testing as appropriate.

Research Area II – Reduced Development Costs of Existing Resources – New products continue to be developed for enhanced oil and gas recovery, but the application of these new tools to unconventional gas needs to be tested. In addition, new products specific to unconventional gas production need to be developed. Coordinated with the Group I projects should be technology field test and technology development activities that include:

- Development and maintenance of a national database of unconventional gas petrophysical information, reservoir data, technology test results and relevant production statistics designed for ease of access by producers and researchers.
- Identification of best fit (new but under development) technology for the problem being addressed followed by a field test for effectiveness. (e.g., microhole horizontal technology);
- Development of production prediction and optimization protocols based on local reservoir requirements, that can help to predict permeability and identify and determine the importance of natural fractures at the local level;
- Development and testing of new well stimulation and completion procedures, including new completion fluids, unbalanced drilling and completion technologies, and new perforating technologies;
- Development of a portfolio of new unconventional gas well construction technologies, each with a development and commercialization plan that undergoes rigorous process review on a continuous basis to maintain relevancy and assure product delivery to the market; and

Research Area III – Crosscutting Topics – Coordinated with Area I and II activities, a crosscutting set of projects should be undertaken to address





environmental, manpower and basic research needs. Items that might be undertaken include:

- An ongoing series of dissemination workshops with a geologic basin focus, where the results of the research program are highlighted and research relevancy assessed;
- A manpower development project coordinated with appropriate academic institutions and regional producer organizations; and
- Addressing environmental and land use issues associated with development of unconventional resources
- Basic research to provide breakthrough ideas that can be developed for application with a mid-term timeframe (5 years), based on needs identified within the program.





1. Workshop Goals and Objectives

The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) sponsored a series of three workshops to obtain input on current industry research and development needs for unconventional gas. In order to encourage participation from stakeholders working in various regions of unconventional gas resources in the continental United States, workshops were held in Houston, TX, Golden, CO and Pittsburgh, PA. To promote an informal discussion atmosphere, attendance was limited to approximately 25 people per session. Invitations were sent via e-mail to individuals representing a cross-section of the producing companies, service companies and research organizations in each of the regions.

1.1 Rationale

Historically, industry groups and government agencies such as the Energy Information Administration (EIA), National Petroleum Council (NPC), United States Geological Survey (USGS), Mineral Management Services (MMS), and Potential Gas Committee (PGC) have studied natural gas supply and demand trends and projected future demand under various price/growth scenarios. The latest reports by these organizations include the Annual Energy Outlook (EIA, 2005), Balancing Natural Gas Policy (NPC, 2003), and Potential Supply of Natural Gas in the United States (PGC, 2003).

It is imperative for economic growth and national security that a significant portion of this supply increase be derived from domestic sources, a goal that can only be achieved through technological advancements that will allow domestic unconventional gas resources to be more efficiently developed.

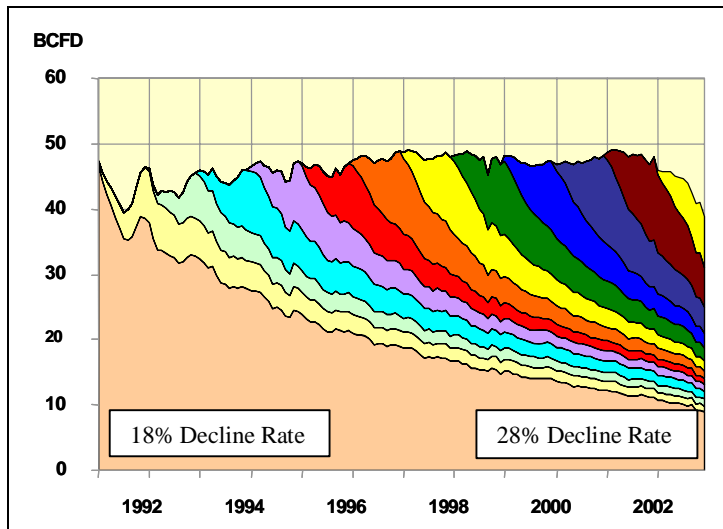
(Potential Supply of Natural Gas in the United States, PGC, 2002)

Projections of price and annual domestic production and consumption of natural gas face difficulties arising from uncertainties inherent in modeling assumptions relative to population growth, economic cycles, and technology advances in the U.S., as well as global economic conditions and geopolitics. Nonetheless, the common conclusion of all these studies is that natural gas

production in the United States must be increased by as much as 40% to meet future demand. A significant fraction of the needed production increase is expected to come from unconventional natural gas resources.

Production data over the last decade indicates that the average size of new discoveries is decreasing. Figure 1 exhibits the decline rate for fields of different

Figure 1 - Decline Rate for Different Vintage Fields





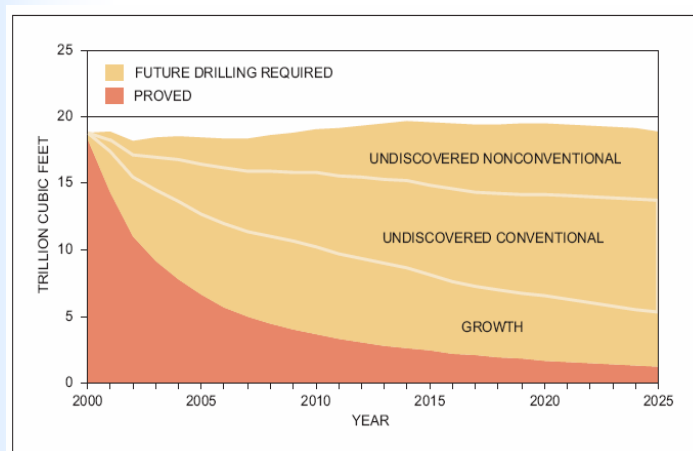
vintages since 1991. The increase in decline rate implies that the giant prolific U.S. fields have already been discovered and produced. Thus, future gas production must come from harder to find and more difficult to produce accumulations.

In light of these observations, the National Petroleum Council, in their 2003 study of natural gas supply (NPC, 2003), has stated that *“traditional North American producing areas will provide 75% of long-term U.S. gas needs, but will be unable to meet projected demand”* thus, *“growth in U.S. natural gas supplies will depend on unconventional domestic production, natural gas from Alaska, and imports of LNG.”*

Development of additional production from unconventional resources has the added benefit of maintaining the security of the U.S. gas supply. While imported LNG certainly has a role in meeting the natural gas needs of the U.S., the development of a stable and secure domestic gas resource base will prevent the natural gas supply in the

U.S. from becoming subject to the same geopolitical forces that affect the oil supply.

Figure 2 - Projected Lower-48 Production by Resource Category (NPC, 2003)



With these considerations in mind, and contingent upon the development of advanced technologies, the U.S. unconventional gas resources are projected to provide a significant percentage of the lower-48 gas production in the future. As shown in Figure 2, the 2003 NPC study projects that unconventional gas production derived from new fields will total approximately 5 tcf/year by the year 2025.

The 2003 NPC study also projects that technology advances through 2030 could increase the technically recoverable U.S. natural gas resource by over 30% (Table 1).

Table 1 - Technically Recoverable Onshore Natural Gas for the Lower-48 (tcf)*

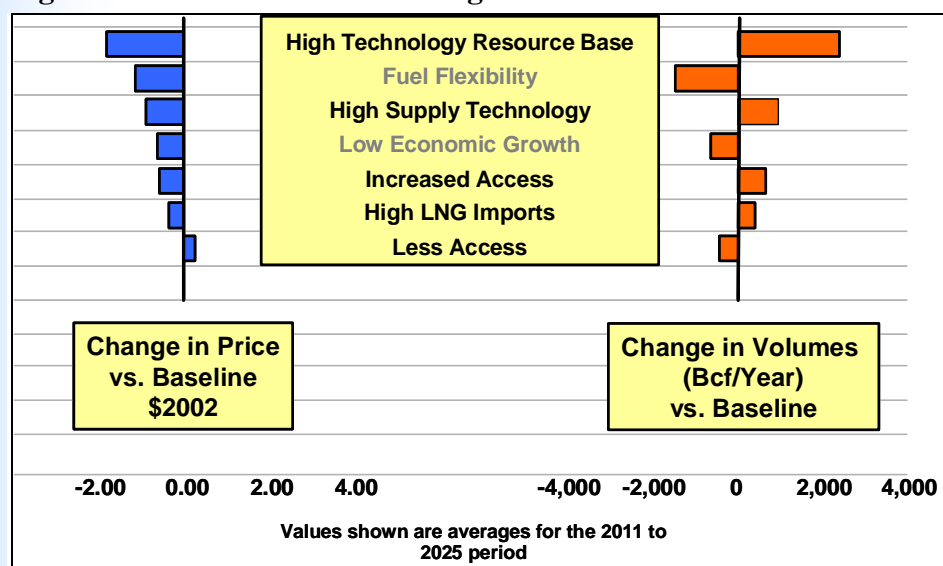
Technology Level	Category	
Current	Proven Reserve as of Dec. 2001	145 tcf
	Potential Growth of Proven Reserve	148 tcf
	Potential Undiscovered Conventional Resources	189 tcf
	Potential Undiscovered Unconventional Resources	282 tcf
	Total Technical Resource	764 tcf
Future	Total 2015 Technology	839 tcf
	Total 2030 Technology	1006 tcf

*Source: NPC, 2003





Figure 3 - Factors that affect Change in Natural Gas Price and Volume



significant factors affecting gas price and production (Figure 3).

Advanced technologies developed during the past two decades have been keys to unlocking natural gas resources such as coalbed methane and tight gas sands. Nonetheless, a number of critical tools and technologies needed

for characterization of, and production from, unconventional reservoirs remain to be developed. For example, better identification of pay zones and determination of permeability in tight reservoirs are essential factors for reliable economic evaluation and risk assessment. In addition, there are substantial opportunities for improving gas well completion and gas production technologies to increase the amount of natural gas available from deep and tight resources. Gas shales represent another emerging resource that has not been developed to the same extent as tight sands and coalbed methane. However, full exploitation of shale gas will require substantial development of new exploration and production technologies.

1.2 Near-Term vs. Long-Term

Development of an additional 4 tcf per year of production from unconventional resources is a significant task. Part of the additional production will come from the traditional unconventional gas resources such as tight sands, basin-centered gas, coalbed methane and gas shales, but additional resources such as deeper reservoirs must also play a significant role. Additionally, basins that have not been developed because of access, environmental or technology constraints will need to be evaluated in light of developing technologies. An effective strategy for meeting the production goals will involve not only the near-term augmentation of current production through the enhancement of existing technologies, but will also include the longer-term development of technologies that will enable new production from unconventional areas.





The near-term research and development must be built on a foundation of past success and aim at advancing technologies that to date have resulted in the production of about 4 tcf of gas per year from coal seams and tight sands. Research and development efforts along the near-term path would include both minor adjustments of operational procedures for achieving incremental improvements as well as opportunities for new technologies to increase production from existing resources.

The longer-term path would lead toward the discovery of larger natural gas accumulations in unconventional settings such as deep sedimentary basins, frontier basins and areas where surface conditions have hampered exploration.

1.2.1 Long-Term Activities

The long-term activities identified in the workshops are intended to characterize unconventional natural gas resources at a national scale and develop the needed technologies for their exploration and commercial production. Work toward achieving this objective might begin with study and prioritization of all major sedimentary basins in term of their natural gas accumulation and selection of specific basins for detailed studies.

Detailed basin-level projects could include comprehensive geological and geochemical studies to be followed by drilling of a number of research wells for verification of geological assessments and identification of technology needs for economic exploration and production from the target resource or formation. The final stage of the long-term research element is the development of resource-specific tools, techniques, and methodologies

1.2.2 Near-Term Activities

As near-term objectives, the workshop participants identified the development of technologies that increase efficiency, reduce the cost, and alleviate environmental concerns relative to exploration and production of unconventional natural gas. The specific technology areas identified by the industry and academic experts during the workshops are documented in Section 3. Work toward meeting these objectives will involve selecting a number of high impact technologies, pursuing their development, and finally field testing and demonstrating the results. Industry participation in these efforts will be essential. Ideally, industry participation will not be limited to cost sharing of the technology development efforts but will include field data acquisition and testing through cooperative research wells.

1.2.3 Crosscutting Topics

Crosscutting technology that overlays all of the technology needs should be undertaken as a third component of a research plan. Topics include basic research, technology dissemination, manpower issues and environmental mitigation and land use issues. The essential elements of these areas are detailed below.

- There is a need for some basic research devoted to understanding the physical, chemical, and flow properties of unconventional natural gas reservoirs. Results





from these efforts would provide fundamental design criteria for new and innovative technologies as well as advancements in the state-of-the-art methods and techniques applicable to unconventional natural gas resource development.

- Due to economic conditions in the energy industry over the past decade, student enrollments in the geosciences and petroleum engineering departments of most universities in the U.S. have been very sparse. As a result, as aging technical experts leave the arena, the industry will face a severe shortage of technical staff. It is therefore imperative to take serious actions aimed at encouraging new students to enter fields of study related to oil and gas exploration and production. In addition, an unconventional gas research program should incorporate extensive targeted training through workshops and short courses. The program can help maintain the vitality of the technical workforce through hands-on involvement of industry and academic participants in development and application of new tools and techniques, and implementation of new approaches.
- Environmental factors may impose limits on the areas that are available for unconventional gas development. Thus, another key element of the program is the development of techniques and approaches for minimizing the environmental effects of exploration and production activities.
- Effective and timely technology transfer and information dissemination is essential. These efforts would begin at the start of the work by soliciting industry participation and continue through a periodic review and reevaluation process. These efforts would also include archiving and timely dissemination of raw and processed data.





2. The Unconventional Gas Resource

A key element of selecting a portfolio of research and development projects is the estimation of risk/reward ratios. In recent times, the E&P industry has collectively tended to minimize technological risk and accept relatively modest rewards. The net effect of such an approach is a progression of incremental technology improvements that require an extended time for research projects to reach a level of significant impact. It is doubtful whether this conservative approach can reach the goal of doubling unconventional gas production within 15 to 20 years. To achieve this expected additional production, a sizable R&D effort must be devoted to high reward projects with associated high risks. For example, R&D aimed at discovery and development of the undiscovered fields that are estimated to contain 282 tcf of technically recoverable gas (NPC, 2003) requires detailed studies of multiple candidate basins, from which only one or two may prove to yield significant gas.

A proven approach to maximize benefit from research funds is industry participation and piggy-backing of research tasks on exploration and development wells being drilled by the industry. While providing huge leverage for limited R&D funds, these cooperative wells also function as a means of highly effective technology transfer. Industry participation in research wells and field demonstrations generates interest and early acceptance, while maintaining the relevancy of the research at all times.

2.1 Resource Description

Unconventional natural gas resources are best described as those gas accumulations that are hard to discover, characterize, and commercially produce by common exploration and production technologies. These resources are typically located in heterogeneous, extremely complex, and often poorly understood geologic systems. For example, it is almost impossible to identify tight lenticular gas bearing sand bodies by state-of-the-art seismic imaging or to determine their flow properties from petrophysical well surveys. Furthermore, because of low formation permeabilities, establishing gas flows at commercially viable rates requires costly production stimulation operations. These types of considerations increase the financial risk associated with unconventional gas exploration and development projects, and divert industry investment from these resources.

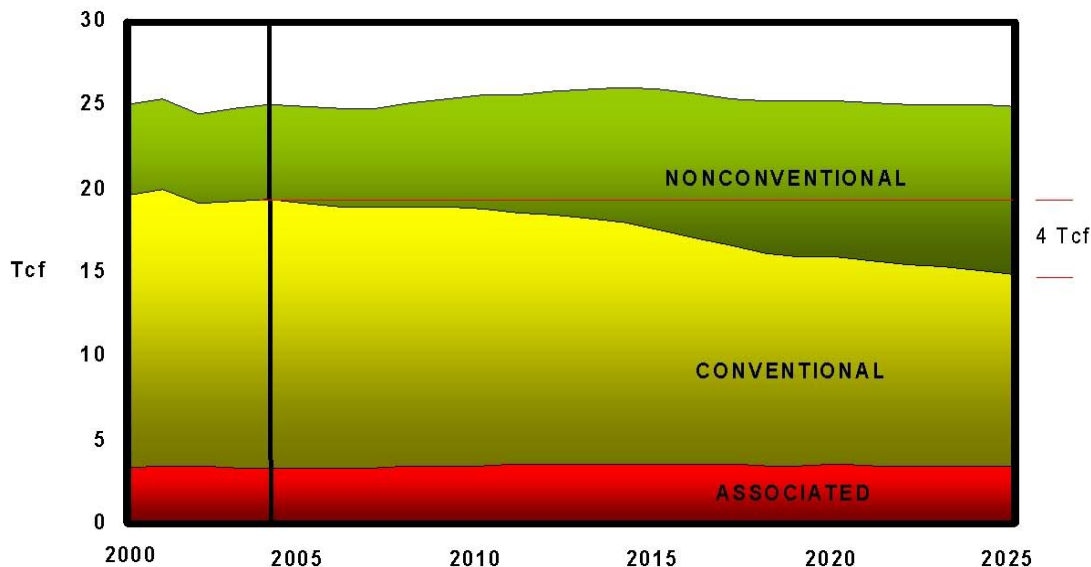
It is interesting to note that the “unconventionality” of these resources; be they coal gas, tight sand, tight carbonates, shale, or deep gas, is a relative term. As technologies develop, the simpler segments of these resources become readily producible and shift toward the conventional resource base. For example, natural gas production from coal seams was negligible in 1990, but the development of coalbed methane technologies brought annual production to 1.6 tcf by 2002. Nonetheless, technologies for exploitation of deeper and thinner coals have not yet been developed, leaving a great portion of coal seam gas within the unconventional resource base.

Production from the major U.S. unconventional gas resources exceeded 4 tcf in 2004 and is expected to grow an additional 4 tcf by 2025 (Figure 4 on the following page). Each of these resources is discussed in greater detail following Figure 4.





Figure 4 - Non-Arctic U.S. and Canadian Production Outlook



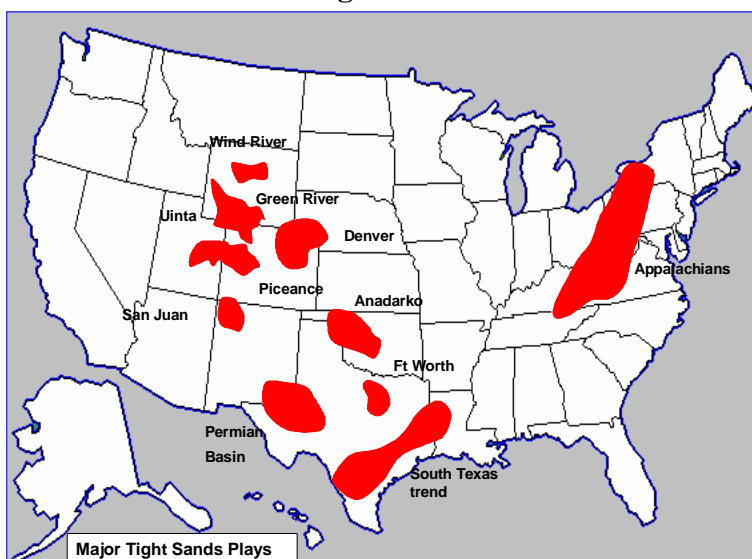
2.1.1 Tight Gas Sands

Tight gas sands (Figure 5) are by far the most abundant of all U.S. unconventional gas resources (a more detailed resource map is provided in GTI, 2001a). Production from tight gas sands averages 3.2 tcf per year. Of that amount, approximately 50% comes from the South Texas trend. An additional 30% comes from the Rocky Mountain Region, with most of the rest coming from the Permian and Anadarko Basins. Less than 2% comes from the Appalachian Basin.

Estimates of the economically recoverable reserves (using current technologies) are approximately 185 tcf, and estimates of undiscovered reserves are as high as 350 tcf).

Tight gas sands are distinguished from conventional gas sands by their very low permeability. They require production stimulation – usually through hydraulic fracturing - to flow at commercially viable rates. Because of their low permeability, the bulk of the production from these reservoirs is through narrow natural fractures that act as flow conduits.

Figure 5 - Basins with Major Gas Production from Tight Sands





Advances in hydraulic fracturing technology during the last two decades have been the major factor in increasing the production from this type of reservoir. However, several technological challenges remain to be met. For example, because hydraulic fractures normally grow parallel to the open natural fractures, they intersect only a few of the open fractures and therefore, the flow rates seldom reach their potential maximums.

Another significant issue relative to drilling and completion in tight sands reservoirs is permeability reduction resulting from physical and chemical reactions between the reservoir rock and the drilling and fracturing fluids.

Identification of gas bearing zones by surface seismic imaging and seismic attribute analyses have had reasonable success in conventional reservoirs but have seen limited success in tight sands. The same holds true for identification of pay zones and estimation of gas saturation by well logging and petrophysical analysis techniques.

The net effect of these technical challenges has been higher exploration risk and low production rates that diminish the commercial value of tight gas wells.

2.1.2 Gas Shales

Methane is stored within shales in pore space, microfractures, and as molecules adsorbed on clay particles. However, because of the extremely low permeability of shales, natural flow from shale reservoirs is very slow, rendering deeper drilling and completion non-commercial at this time. As shown in Figure 6, five major shale formations have been identified as the most promising for production of shale gas resource.

Historically, the shallow shale gas wells such as those drilled in the Devonian shale of the Appalachian region have been low rate producers but have been productive for many decades. It is estimated (Colorado School of Mines, 2003) that several hundred thousand wells have been drilled in the Appalachian Basin alone, most to depths of less than 5,000 feet. Only 11 wells have been drilled deeper than 15,000 feet, and only 10-15% of the potential hydrocarbon-producing sedimentary rocks have been tested. Potential resources in the Appalachian Basin are estimated to be 45 tcf. Estimates for other basins are described in Table 2:

Figure 6 - Major Fractured Shale Gas Plays

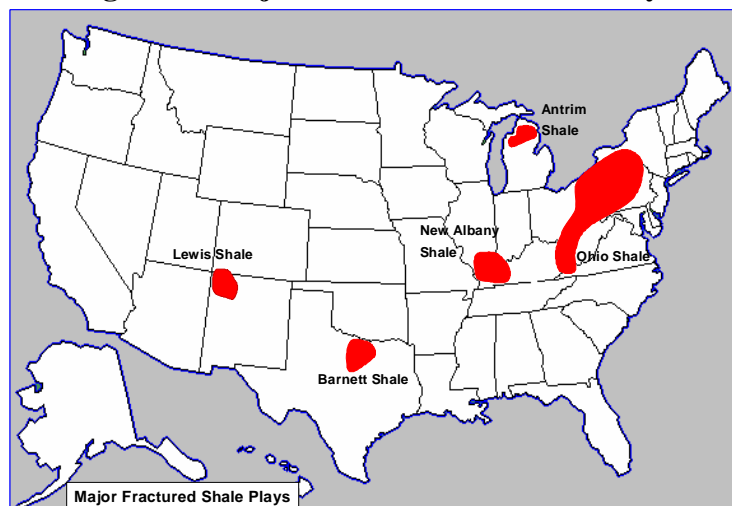




Table 2 – Potential Continental U.S. Shale Gas Resources

Formation	Location	Estimated Resource	Reference
Appalachian	OH, PA, NY, WV, KY, VA	45 tcf	PGC, 2003
Antrim Shale	MI	5.6 tcf	PGC, 2003
New Albany Shale	IL, KY, IN	5.4 tcf	PGC, 2003
Barnett Shale	TX	4.8 tcf	PGC, 2003
Lewis Shale	NM	24 tcf	PTTC, 2004

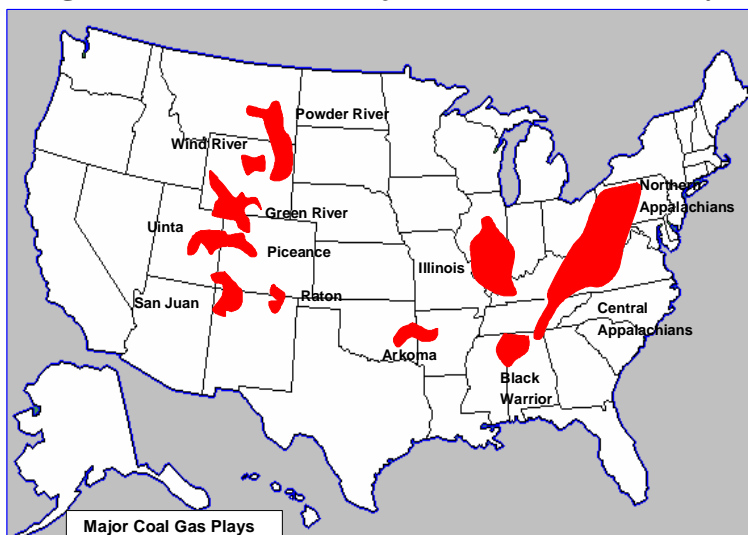
The advent of horizontal drilling and advanced hydraulic fracturing has resulted in substantial production from some shale formations such as the Barnett Shale of the Fort Worth basin in Texas. More than 2,000 wells have been drilled in the Barnett and estimates of total reserves are as great as 1 tcf for every 7 square miles of the Basin (AAPG, 2002). However, because of very low matrix permeability, the flow of gas from shale formations is often governed by the nature and extent of natural fractures, and recoveries from the Barnett Shale are currently estimated as only about 7%. Similar issues exist for the other shale gas formations.

Additional resource characterization is needed to determine the full potential of the fractured gas plays, along with research to determine the best means of stimulating increased production from these tight formations.

2.1.3 Coal Seams

Production from the coalbed methane resource (Figure 7) experienced a dramatic increase during the last decade. (GTI, 2001b provides a more detailed resource map). Annual production increased from 0.2 tcf in 1990 to over 1.6 tcf by 2004. The total coalbed methane resource in the continental U.S. is estimated to be 703 Tcf (Figure 8 on the

Figure 7 - Location of Major Coal Seams Gas Plays



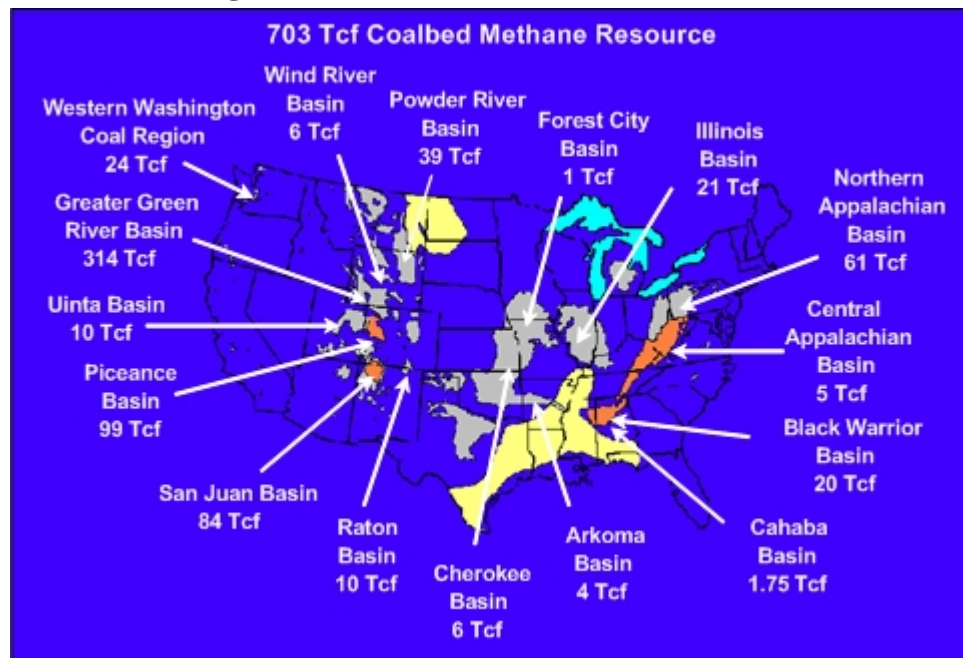
following page) Recoverable coalbed methane resources are estimated to be 63 tcf from known resources, and an additional 110 tcf from as yet undiscovered resources.

In addition, Alaska has estimated recoverable reserves of 57 tcf, and total in-place resources of 1,045 tcf. Canada has an additional 538 tcf of estimated in-place coalbed methane, and drillers are actively working formations in Alberta and Saskatchewan.





Figure 8 – Continental U.S. CBM Resource



Accumulation of methane in coal seams differs from that in other sedimentary rocks in that the gas molecules are adsorbed to coal particles, as opposed to occupying the pore space as a gaseous phase. This adsorption of methane to coal is pressure dependent. As the pressure is reduced, the gas is desorbed and can flow through the coal cleat system. The common practice in coalbed methane (CBM) production involves dewatering of the seams to reduce the ambient pressure. It is not unusual to pump water for up to one year before any methane is produced.

In spite of the success of CBM development in many regions, projects in new areas face many difficulties. For example, the *in situ* permeability of coal seams - which govern the dewatering and degassing processes - cannot be determined prior to drilling with any degree of reliability, and well placement in thinner coal seams faces major difficulties. In addition, the disposal or beneficial use of water produced during CBM production can present challenges that are dependent on regional conditions.

Another significant feature of coal seams is their high affinity to carbon dioxide to the extent that when coal seams with adsorbed methane are exposed to carbon dioxide, CO₂ molecules replace the adsorbed methane molecules. This feature has been the focus of attention because coal seams could concurrently serve the purposes of carbon dioxide sequestration and coalbed methane production projects. The selective adsorbing properties of coals are the principal physical phenomenon underling the enhanced coalbed methane (ECMD) projects through CO₂ sequestration operations. However, the diffusion process in methane- CO₂ mixtures of variable relative concentrations within the cleat and pore systems is not fully understood necessitating fundamental research and development on this process.

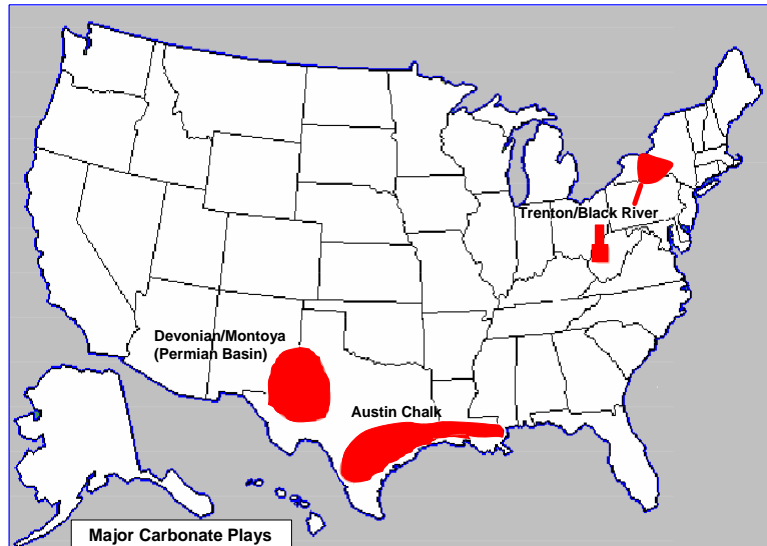




2.1.4 Low Permeability Carbonates

Figure 9 shows the major locations of low permeability carbonate plays in the Continental United States. The largest of these formations is the Austin Chalk, which runs from near Laredo Texas through eastern Louisiana. Other carbonate formations are found in West Texas, southeastern Ohio and southern New York. Wells in the Austin Chalk are currently yielding 1 to 3 bcf per well per year.

Figure 9 - Major Low Permeability U.S. Carbonate Plays



Evaluation and characterization of carbonate reservoir rocks, be they shallow or deep, low or high permeability, has been problematic. For low permeability carbonates, the issues are most difficult, because subtle property changes that affect the flow properties of the reservoir units are below the resolution and capabilities of current imaging technology. Nonetheless, recent successes in low permeability carbonate plays in the Appalachian Basin, South Texas, and the Permian Basin have clearly demonstrated the potential of this resource.

One source of problems in understanding and characterizing carbonate reservoirs is the fact that, except for reservoirs where granular dolomites contribute to porosity and permeability development, tools and techniques that are successful in characterizing sandstone reservoirs do not produce reliable results in carbonate plays. This is because the major flow conduits in carbonate reservoirs are natural fractures. In the absence of any proven and reliable technology for fracture identification and characterization, well placement for carbonate reservoirs bears a high risk factor. Further, in the case of tight carbonates, gas stored in the fracture space initially flows at high rates, but production may fall off quickly as the flow from the tight pore spaces replenish the fracture space at a very slow rate. Reliable reservoir assessments may therefore only be possible after a relatively long period of time. The net effect has been that carbonate formations tend to be higher risk plays, thus discouraging exploration for the resource.

2.1.5 Deep Gas Plays and Basin-Centered Gas

Deep gas refers to reservoirs deeper than 17,500 feet. Areas of significant production potential in the U.S. include the Anadarko Basin, northern Rocky Mountains, and the Gulf Coast region, as shown in Figure 10. The high overburden pressure imposed on





deep gas resources creates reduction in porosity and permeability. However, the reservoir pressures are also high, compensating for the reduced pore space.

Exploration in deep gas plays face numerous difficulties arising from inaccurate geologic models, reduced resolution of seismic techniques because of the great depths, and pay identification difficulties.

Drilling and completing deep gas wells are very costly due to the extremely high temperatures and pressures and hard rock encountered.

The United States Geological Survey (USGS) defines basin-centered or continuous-type accumulations as “large single fields having spatial dimensions equal to or exceeding those of conventional plays (Popov, et. al., 2001). They cannot be represented in terms of discrete, countable units delineated by downdip hydrocarbon-water contacts (as are conventional fields).” In 1995, the USGS defined 61 continuous-type plays with oil and gas reservoirs in sandstones, shales, chalks, and coals. Of the 61 identified plays, 47 were assessed by USGS in 1998-2000 of which 33 were gas plays.

Estimates of technically recoverable gas resources from continuous-type sandstones, shales, and chalks range from 219 Tcf (95th fractile) to 417 Tcf (5th fractile), with a mean estimate of 308 Tcf. It must be noted that these estimates may overlap those given for deep and other unconventional resources to some extent. Areas with deep and basin-centered gas potential are typified by thick sedimentary sections embodying several reservoir horizons with reservoir pressures ranging from under-pressure to over-pressure conditions.

Figure 11 exhibits the location of major basin-centered gas systems in the United States. The better known deep and basin-centered gas accumulations occur in the Rocky Mountain region and Anadarko basin where the industry’s efforts toward field extension and deeper pool exploration have resulted in sizeable discoveries. However, numerous sedimentary basins in the US have remained virtually unexplored for several technical and economic reasons. For example, near surface conditions in parts of the Permian Basin or the Columbia River Plateau have rendered conventional surface seismic virtually useless. In the meantime low gas prices that prevailed until lately did not justify the high economic risks associated with costly 3-D seismic surveys or expensive exploration and stratigraphy wells.

Figure 10 - Major Deep Gas Plays. (Source: PGC)

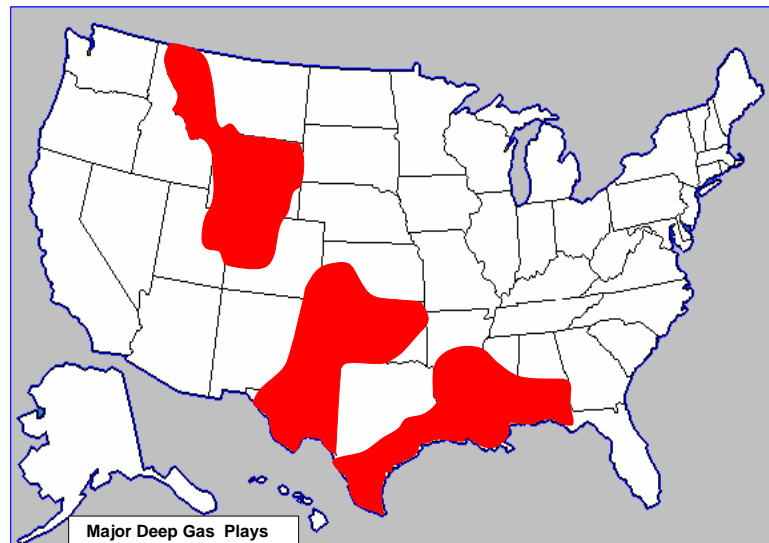




Figure 11 - Basin-Centered Gas Systems of the U. S. (Source: USGS, Open File Report OF 01-135)





3. Industry Workshop Results

3.1 Workshop Overview

The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) sponsored a series of three workshops to obtain input on industry research and development needs for unconventional gas. In order to encourage participation from unconventional gas resource stakeholders working in various regions of the continental United States, workshops were held in Houston, TX, Golden, CO and Pittsburgh, PA. To promote an informal discussion atmosphere, attendance was limited to approximately 25 people per session. Invitations were sent via e-mail to individuals representing a cross-section of the producing companies, service companies and research organizations in each of the regions. The list of attendees for each of the workshops is provided in Appendix A. Comments received from industry attendees indicated that the producers and service companies represented were either currently involved in unconventional gas E&P or were considering investment in the development of unconventional gas resources.

As an example of a recent effort to identify key technology needs for unconventional gas development, workshop participants were each provided, prior to the workshop, a copy of a document developed by New Mexico Tech and GTI (Engler, et. al., 2003). Participants were advised that the workshop would be directed toward identifying research needs and prioritizing those needs.

At each of the workshops, a key driver that would improve industry's ability to economically develop unconventional gas was identified. In Houston, it was the need for more "basic" research directed toward understanding the fundamental factors that control production of unconventional gas. The need to do a better job collecting and disseminating unconventional gas production information was emphasized at the Golden workshop. In Pittsburgh, the group emphasized the need for a better understanding of the reservoir. Each of these sessions also identified and prioritized other important areas for unconventional gas technology investment, which are covered in more detail in the following sections.

3.2 Workshop Structure

Each workshop opened with a presentation by a NETL representative, summarizing the DOE perspective on the role of unconventional gas for meeting U.S demand, and highlighting past cooperative efforts that led to increases in unconventional gas production. A guest speaker then provided additional thoughts regarding the role of unconventional gas and the need for new technology to support additional production. After these talks, which typically lasted about an hour, GTI led a 1.5 to 2 hour brainstorming session to identify areas that could have the most impact on unconventional gas production.

During a subsequent break, GTI consolidated the ideas into a smaller set of non-overlapping concepts that could be prioritized by the group. The objectives of this step were to capture discussion elements that were not well reflected on the original lists, as well as to combine similar topics so that the voting was not split among





multiple topics that represented facets of the same concept. The summary topics were then discussed among the workshop participants prior to voting to assure that the consolidated list captured the results of the brainstorming and associated discussions. The summary topics were edited as required in response to participant feedback.

The concepts were then prioritized through a voting process. Each participant was given five votes, which could all be "voted" towards one research concept, or distributed as desired amongst the various topics. The votes for industry and non-industry participants were recorded separately. The votes were recorded by sticking self-adhesive colored dots on flip chart paper on which the concepts were described, so all participants voted more-or-less simultaneously, but not secretly.

Following the voting, the results were summarized and discussed with the group, along with the results of earlier workshops. During the first workshop (Houston) a second brainstorming session was held, with the intention of prioritizing specific technology needs rather than general areas of research. While the results of that session are included in this report, the topics were difficult to define in a way that made the voting meaningful in the limited time available. In the second and third workshops, we eliminated the second brainstorming session and devoted additional time to generating the topics and discussing the results of the single brainstorming session. The workshops began at 8:30 AM and were finished by 2:00 PM.

3.3 Workshop Results

3.3.1 Workshop #1 – Houston, TX – July 19, 2005

3.3.1.1 Unconventional Gas Challenges Identified in Brainstorming Session

Unconventional Natural Gas Challenges - Brainstorming Ideas - Session #1

- Support entrepreneurial efforts that provide innovative technology
- Support fundamental research versus application driven
- The independent producer needs assurance that gas can be sold. Infrastructure must allow revenue in short period
- Improved access to pipelines/infrastructure
- Last-mile transportation, to provide a revenue stream prior to infrastructure development
- On-site electrical power generation - do solutions exist?
- Portable or small scale LNG
- Promote the application of novel but existing solutions
- Public investment to share risk of new technology applications
- Impact of technology on economics - e.g. apply seismic to increase SEC bookable reserves
- Understanding unconventional "Basin-centered" gas - what are the issues?
- Finding, evaluation or production?
- Value of resource-based studies. Appropriate for public funding?
- How are resource assessments tied to economics?
- Why are we not working in Basin X? Answer this question for all basins





- Increase recovery from each resource
- Why has increased drilling not led to more production - focus on smaller targets?
- Reduce production and development cost. Need more information for good investment decisions
- Reduce the cost to evaluate unconventional gas resources
- Technology to develop reserves with fewer wells
- Accumulate and evaluate Best Practices
- Best Practices versus Optimum Practices - Is the best that we are doing really the best that can be done?
- Provide a place and approach to test new technologies
- Evaluation to assist in the commercialization of new technologies
- Accelerate the learning curve for applying new (or in new resources) technology
- Study programs like MWX to determine the metrics for a successful program

The 26 discussion topics identified above were consolidated as described in Section 3.2 into the following 13 summary topics for prioritization..

Summary Topics for Prioritization from Brainstorming Session #1

- **Entrepreneurial Support** - Support entrepreneurial efforts that provide innovative technology
- **Infrastructure Development** - Development of infrastructure for gas production and distribution in frontier areas
- **Basic Research** - Basic research leading to a fundamental understanding of the properties of unconventional gas reservoirs, and how those properties drive optimum exploration and production approaches
- **Quantify Impact of Technology** – Studies assessing the economic impact of new technology development and application
- **Technology Transfer**
- **Field-Based Testing** – Large-scale field experiments (e.g., DOE Multi-Well Experiments (MWX) and the GRI cooperative Staged Field Experiments (SFE)
- **Personnel Training and Development**
- **R&D Monitoring/Research Coordination**
- **Best Practices** – Identify and disseminate the Best Practices for E&P operations in various unconventional gas resources
- **Test Site** – Support the operation of facilities such as the Rocky Mountain Oilfield Testing Center (RMOTC) for the evaluation of new technologies
- **Resource Characterization** – Detailed studies of specific unconventional gas resources to determine why certain practices are successful or unsuccessful. The goal is to develop an understanding sufficient to apply knowledge to new reservoirs without extensive trial and error to develop best practices
- **External Technology** - Apply advanced technology from other industries
- **Consortium Sponsorship** – Leverage research funds by joining in consortia





Of the 27 participants in the Houston workshop, some had to leave early, and the RPSEA and GTI representatives did not participate in the voting. A total of 103 votes were cast by 21 participants. Table 3 summarizes the results.

Table 3 - Research Priorities from the Houston TX Workshop – Session #1

Summary Topic	Total Votes	Industry Votes	Others
Basic research	25	15	10
Field-Based Testing	21	9	12
Resource Characterization	17	11	6
Infrastructure Development	9	7	2
Personnel Training and Development	7	3	4
Test Site	6	5	1
Technology Transfer	5	3	2
Entrepreneurial Support	4	3	1
Quantify Impact of Technology	3	2	1
External Technology	3	3	0
R&D Monitoring/Research Coordination	2	1	1
Consortium Sponsorship	1	1	0
Best Practices	<u>0</u>	<u>0</u>	<u>0</u>
<i>Totals</i>	103	63	40

The first three topics together received considerably more votes than the remaining ten combined. In both the voting and the associated discussion, the need was expressed for achieving a level of understanding that would enable us to base our exploration and development approaches on a sound physical understanding of the factors controlling production rather than on the empirical results associated with large numbers of sub-optimum wells.

In the second Houston session, the participants were asked to identify more specific technology challenges associated with unconventional gas development. The brainstorming session produced the following list.

Unconventional Natural Gas Challenges - Brainstorming Ideas - Session #2

- Reducing costs – e.g. drilling improvements
- Completing in low-pressure gas sands
- Deep CBM, high-pressure, high-temperature gas sands
- Formation evaluation in shales, coals, carbonates, etc.
- Net pay identification
- Unloading and lifting technologies
- Understanding the basic physics behind operations versus empirical approach
- Production optimization
- Microhole drilling - production, exploration and near surface extension reach
- Low-cost cased hole pressure evaluation
- Production analysis in stacked reservoirs





- Integrated reservoir characterization – geologic, seismic, engineering, petrophysical and reservoir size (scale) issues
- Evaluation of welldog
- Genesis and preservation of natural fracture systems
- Effect of natural fractures on reservoir properties

Available time for the second session was limited, with limited opportunity for group discussion before voting. The same approach of five votes per person, distributed in any desired fashion, was used in the second session. Table 3 shows the results.

Table 4 - Research Priorities from the Houston TX Workshop – Session #2

Summary Topic	Total Votes	Industry Votes	Others
Integrated reservoir characterization – geologic, seismic, engineering, petrophysical and reservoir size (scale) issues	15	8	7
Understanding the physics behind operations	15	10	5
Formation evaluation in shales, coals, carbonates, etc.	11	8	3
Net pay identification	10	7	3
Completing in low-pressure gas sands	8	3	5
Reducing costs – e.g. drilling improvements	6	4	2
Unloading and lifting technologies	6	5	1
Deep CBM, high-pressure, high-temperature gas sands	5	4	1
Production optimization	5	3	2
Microhole technology, production, exploration and near surface extension reach	5	4	1
Effect of natural fractures on reservoir properties	5	3	2
Production analysis in stacked reservoirs	4	2	2
Genesis and preservation of natural fracture systems	<u>3</u>	<u>2</u>	<u>1</u>
Low-cost cased hole pressure evaluation	<u>2</u>	<u>2</u>	<u>0</u>
Evaluation of welldog	<u>0</u>	<u>0</u>	<u>0</u>
<i>Totals</i>	100	65	35

Not surprisingly, the second session reflected some of the same themes as the first. Tools for integrated reservoir characterization, along with formation evaluation ranked high on the list. Unquestionably, the topics listed are all important for the successful development of unconventional gas resources.

After this session, we made the decision to concentrate on a single brainstorming session in subsequent workshops, to allow the participants more time for detailed discussion of the results.





3.3.2 Workshop #2 – Golden, CO – August 9, 2005

3.3.2.1 Unconventional Gas Challenges Identified in Brainstorming Session

Unconventional Natural Gas Challenges - Brainstorming Ideas

- Predictability of results from completion/stimulation operations
- Understanding natural fractures – location, orientation and effect on production
- Defining ways to achieve effective public/private partnerships
- Water issues in the Greater Green River Basin (treatment and/or disposal)
- Coalbed methane in “deeper” zones
- Moving known “gas-in-place” into “reserves”
- Increasing confidence in gas-in-place estimates
- Basin-scale petroleum systems studies
- Pay for, collect and analyze data that operators would not otherwise collect.
- Build an electronic database of existing “paper” data collected through past programs at DOE, GTI and elsewhere
- Refine gas-in-place, technically recoverable resource, economically recoverable resource, reserves and production estimates, including uncertainty. Collect the required data and develop the methodology
- Improve production estimates to define well life
- Develop advanced well construction, such as the pinnate method, for a better connection to the reservoir
- Develop a more meaningful definition of “net pay”
- Develop methodology and tools for sophisticated 3-D petrophysical reservoir modeling, leading to better prediction of production
- Improve insight into formation damage from drilling, completion and stimulation
- Sharing “Best Practices”
- Conduct basin-wide systems studies in unconventional gas basins. Develop a model explaining existing well data that can be updated as new wells are drilled. Develop a means to collect and assimilate data from individual operators
- Improve understanding and predictability of the quality of 3-D seismic results
- Conduct source rock studies
- Conduct gas analysis to tie production to the source system
- Collect/analyze data from majors and other operators to avoid permanent loss
- Provide access to data for all, including small independents
- Concentrate on work that will impact supply in long-term
- Database of “Best Practices” to prevent re-inventing the wheel
- Encourage true exploration, in new areas and/or with new play concepts
- Collect data from research consortia
- Update and expand regional and resource-focused atlases
- Influence public policy regarding data collection and availability
- Improve the dissemination of technology, for example, application shallow gas technology from Canada to the Appalachians
- Basic research, for example, DOE’s Multi-Well Experiments (MWX) projects
- Longer term research to fill in the gaps identified by data studies





- Metrics, communication, industry input and accountability for basic research
- Move toward the Canadian model for data collection and accessibility
- Make “raw data” on research projects more available, in addition to published research reports that focus on the analysis of the data

The 36 discussion items identified above were consolidated, as described in Section 3.2, into the following nine summary topics for prioritization.

Summary Topics for Prioritization from Brainstorming Session

- **Basin-Scale Petroleum Systems Studies** - Identify source rocks, migration pathways, timing of petroleum generation and migration, reservoir history and other factors controlling petroleum accumulation basin-wide.
- **Data Collection and Availability** – Develop a system to improve access to data collected by operators. The Canadian model, where operators are required to submit data to the government after a period of time, is one approach. Uses include data mining, basin studies, defining knowledge gaps, avoiding the loss of legacy information and ensuring the value associated with future work.
- **Predictability of Production** – Understand the effects of natural fractures and formation damage. Develop 3-D reservoir modeling tools that allow prediction of production.
- **Advanced Well Construction** – Examples include fishbone drilling patterns, more efficient drilling in hard rocks, improved hydraulic fracturing and stimulation, and methodologies to better link engineering design of wells to reservoir characteristics.
- **Field-Based Testing** – Large-scale controlled field experiments e.g., DOE Multi-Well Experiments (MWX) and the GRI Staged Field Experiments (SFE).
- **Resource Assessment** – Evaluate basins throughout the U.S. for gas-in-place, technically recoverable resource, economically recoverable resource, reserves, and the probabilities associated with these estimates.
- **Best Practices** – Identify and disseminate the Best Practices for E&P operations in various unconventional gas resources.
- **Technology Transfer**
- **Environmental and Land Access** – Develop technological solutions or policy initiatives that improve access to prospective unconventional gas resources. Technological challenges include produced water handling, reducing well footprint, development with fewer wells and other initiatives that reduce the environmental impact of unconventional gas development.
- **Basin-Scale Petroleum Systems Studies** - Identify source rocks, migration pathways, timing of petroleum generation and migration, reservoir history and other factors controlling petroleum accumulation basin-wide.

Basic Research was identified as a tenth topic. However, after debate, participants agreed that each of the summary topics could have a “basic research” element. As an alternative to having **Basic Research** as a voting topic, participants were allowed to specify the fraction of total research dollars that should be devoted to basic research. The average percentage specified by 11 participants was just over 20%.





Of the 24 participants that attended the Golden workshop, 21 voted, as some of the RPSEA and GTI participants abstained from voting. Table 5 summarizes the results.

Table 5 – Research Priorities from Golden, CO Workshop

Summary Topic	Total Votes Received	Industry Votes	Others
Data Collection and Availability	18	11	7
Predictability of Production	15	10	5
Advanced Well Construction	15	10	5
Basin-Scale Petroleum Systems Studies	15	8	7
Environmental and Land Access	14	6	8
Resource Assessment	13	7	6
Field-Based Testing	12	7	5
Best Practices	3	1	2
Technology Transfer	0	0	0
<i>Totals</i>	105	60	45

The group in Golden gravitated to more technology-specific topics than the Houston group, with more detailed discussion of specific technology needs. The consolidation process categorized some of these technology areas, but the list generated in Golden is more focused on technology areas than that resulting from the Houston workshop.

The topic that received the most discussion and votes was **Data Collection and Availability**. Although a large volume of data has been collected during various study and exploration efforts in the western U.S., in most cases the data has not been archived. In the case of publicly available studies, the raw data is often lost after the research reports are published. For proprietary studies or exploration efforts, the data becomes buried in company records and is often lost during moves or mergers. A clear theme of this workshop was that a mechanism to collect E&P data and provide it to the public, subject to a period of proprietary access, would be of great value. The model used in Canada, where exploration data must be submitted to the government (who then makes it available subject to certain conditions) was discussed as one means to increase data access. A system analogous to the Canadian model may or may not be feasible in the U.S., but the workshop participants sent a clear message that they felt there was a significant opportunity to increase the effectiveness of unconventional gas development through better handling of E&P data.

The highly ranked **Predictability of Production** topic has much in common with the **Resource Characterization** topic from the Houston workshop. Specific technology areas that were highly ranked by the Golden participants include **Advanced Well Construction** and **Basin-Scale Petroleum Systems Studies**. The issue of improving land access was also important to western U.S. producers. Studies that evaluate new unconventional gas resources and help identify and quantify investment opportunities were considered positively, as was the concept of field-based testing for technology development and evaluation.





3.3.3 Workshop #3 – Pittsburgh, PA – August 25, 2005

3.3.3.1 Unconventional Gas Challenges Identified in Brainstorming Session

Unconventional Natural Gas Challenges - Brainstorming Ideas

- Conduct resource assessments
- Evaluation of unconventional vs. conventional gas resources
- Perform retrospective studies on the impact of past innovations that enabled new resource development
- Characterization of shale gas plays, such as Antrim, Big Sandy and Barnett. Why do they work, and how can the knowledge gained be applied elsewhere?
- Characterize resources and plays in detail to allow successful methods to be applied in analogous resources
- Environmental factors affecting development in the eastern U.S., including such things as wine tourism and resistance to drilling off the east coast
- Improve access to resources
- Quantify currently inaccessible resources nationwide, not just in the Rockies.
- Evaluate the impact of development regulations on unconventional gas production (e.g. 70 acre spacing for shale in NY State and offshore drilling bans)
- Infrastructure development, including alternatives to pipelines such as small-scale LNG and gas-to-liquids
- Address the constraints on gas production due to rig capacity and manpower.
- Develop personnel and intellectual capital
- Support for college expenses of Petroleum Engineering and Earth Science majors
- Support E&P related university programs
- Encourage geosciences and geology students to pursue E&P careers
- Develop technology and knowledge to increase recovery from existing resources
- Improve our understanding of energy economics; is the business truly cyclical?
- Determine the correct spacing for producing each formation
- Develop better tools for reservoir description and prediction of production
- Lower the cost for reservoir evaluation
- Methodologies to improve the ability to describe and predict production
- Study currently undeveloped resources, such as coalbed methane in Pennsylvania anthracites. Characterize the resource and determine possible development approaches
- Improve methods for produced water treatment and handling
- Develop stimulation methods to improve the performance of marginal wells
- Determine the optimal treatments for a given formation
- Optimize drilling and completion practices to avoid formation damage
- Perform basic studies to answer questions such as “Why must Devonian shale be acidized before hydraulic fracturing?”
- Accumulate and publish “Best Practices”
- Compile information such as core, drill cuttings, well logs and drilling and production data for industry in appropriate databases integrated with GIS





- Improve horizontal drilling and completion technology
- Develop a model for predicting production from horizontal wells that will allow an appropriate economic decision regarding their use
- Address factors such as high steel prices
- Evaluate possible alternatives to high-quality sand for proppants
- Improved methods for determining the vertical intervals producing in a well
- Develop a national gas production database, formation and basin focused and integrated with GIS
- Improve gas dehydration and processing technology
- Develop technologies to re-work old wells (e.g. re-completing bypassed zones)

The 37 discussion items identified above were consolidated, as described in Section 3.2, into the following 15 summary topics for prioritization.

Summary Topics for Prioritization from Brainstorming Session

- **Resource Assessment** - Conduct Assessments to identify new resources (incl. the evaluation of existing resources and new resources that are not currently under development, such as coalbed methane in Pennsylvania anthracite beds)
- **Impact of Past Innovations** - Perform retrospective studies on the impact of past innovations that enabled new resource development
- **Reservoir/Resource/Play Characterization** – Develop a fundamental understanding of the factors controlling reserves and production in a reservoir and apply the knowledge to the development of new resources
- **Access to Resources** – Address the unique environmental factors impacting natural gas development in the eastern U.S. and provide quantitative estimates of the size of the resource base restricted from development nationwide
- **Production Prediction and Optimization** – Develop a methodology to determine the optimum development strategy for a particular reservoir, including well spacing, well construction and treatment and stimulation
- **Infrastructure** – Develop means to economically produce “stranded” gas
- **Manpower Development** – Increase the pool of E&P expertise through support of universities and encouragement of E&P careers
- **Energy Economics** – Address the prediction of energy prices and develop an understanding of the potentially cyclic nature of the energy business
- **Produced Water** – Improve methods for treating and handling produced water
- **Stimulation Technology**
- **Best Practices** - Identify and disseminate the Best Practices for E&P operations in various unconventional gas resources
- **Database Compilation** – Compile E&P data into a nationwide database compatible with GIS systems and widely available to industry; develop and apply data mining methods to extract information from such a database
- **Operational Limitations** – Address operational limitations such as steel prices, sand (proppant) availability and drilling rig availability
- **Gas Processing**
- **Re-working Old Wells** – Develop methods for getting additional production from old wells, such as identifying and re-completing bypassed zones





Of the 16 Pittsburgh workshop participants, 14 voted, as some of the RPSEA and GTI representatives did not participate in the voting. Table 5 summarizes the results.

Table 6 - Research Priorities from Pittsburgh, PA Workshop

Summary Topic	Total Votes Received	Industry Votes	Others
Reservoir/Resource/Play Characterization	12	4	8
Resource Assessment	12	3	9
Database Compilation	12	3	9
Production Prediction and Optimization	10	4	6
Stimulation technology	7	2	5
Manpower Development	5	4	1
Re-working Old Wells	4	2	2
Operational Limitations	3	2	1
Energy Economics	3	1	2
Access to Resources	1	0	1
Infrastructure	1	0	1
Best Practices	0	0	0
Gas Processing	0	0	0
Produced Water	0	0	0
Impact of Past Innovations	0	0	0
<i>Totals</i>	70	25	45

Over 75% of the votes were distributed among the top five topics. These topics include technical issues involving understanding the factors controlling production, as well as the identification and evaluation of new resources. As with the Golden workshop, access to data that is collected but not widely available was ranked highly. It is interesting to note the voting for **Manpower Development** (ranked 6th) in the Pittsburgh workshop. A similar topic received considerable discussion in the Houston workshop, but was clearly a second tier priority.

3.4 Analysis of Results from the Three Workshops

The workshops were structured so that the participants defined their own topics. This approach assured that the topics were aligned with the specific concerns of those attending each workshop. However, the lack of a consistent set of topics makes consolidation of the results from the three workshops difficult. For example, issues identified under **Basic Research** and **Resource Characterization** at the Houston meeting were also mentioned during the discussions on **Predictability of Production** in Golden and **Reservoir/Resource/Play Characterization** in Pittsburgh.

Rather than attempt to define a consolidated priority ranking from the three workshops, we have developed a list of topics that includes the essential elements of the highest ranked topics from each of the three workshops. As each of these topics received strong support from workshop participants, their relative priority is less meaningful than the way in which these high priority topics come together to define technology needs for unconventional gas development.





While we recorded votes separately for industry and non-industry workshop participants, for ease of comparison among the three workshops we used the total votes in our analysis. In general, the highest ranking topics were similar within the two groups.. The greatest differences were observed in the Pittsburgh workshop, which had a limited number of industry participants.

The research topics fall into three groups. The first research area – **Development and Characterization of New Resources** - involves activities that will result in the development of new resources that are not currently the major focus of E&P activity. These activities involve longer-term research, but they have the potential for dramatic increases in reserves and production if significant new resources are identified. The second research area – **Reduced Development Costs of Existing Resources** - includes activities that will lower the cost or otherwise facilitate the development of unconventional gas resources that are known and under some degree of development. These activities have the potential to impact the U.S. gas supply in the relatively near term. Finally, research area 3 – **Crosscutting Topics** – involves those activities with the potential to impact unconventional gas production but that transcend the specific technical issues associated with the first two groups. Each Research Area is described below:

3.4.1 Research Area I – Development and Characterization of New Resources

Resource Assessment – This area includes the evaluation of continental U.S. basins for gas-in-place, technically recoverable resource, economically recoverable resource, reserves, and the probabilities associated with these estimates. The goal is to identify new resources, existing resources that may be under-developed, and unconventional gas resources that are not currently under development, such as coalbed methane in Pennsylvania anthracite beds. This topic was tied for the top ranking in the Pittsburgh workshop, and received a significant number of votes in the Golden session.

Basin-Scale Petroleum Systems Studies - This area includes the identification of source rocks, migration pathways, timing of petroleum generation and migration, reservoir history and other factors controlling petroleum accumulation basin-wide. These sorts of studies help to quantify potential resources and guide exploration in frontier areas where large undiscovered accumulations may be possible. This topic was tied for the second-place ranking in the Golden workshop.

Field-Based Testing – This area includes the conducting of large-scale controlled field experiments such as the DOE Multi-Well Experiments (MWX) and the GRI cooperative Staged Field Experiments (SFE). While their scale and level of effort may vary, controlled experiments are essential for identifying the factors that control resource production. These experiments can eliminate much of the trial and error learning that occurs when one enters a new resource, often with conceptual analogues that may or may not be valid. These experiments may also help solve problems and reduce cost in known resources. This topic was ranked second in the Houston workshop, and received a significant number of votes in Golden. In addition, the **Basic Research** that was ranked first in Houston may often be conducted through well-designed controlled field studies.





3.4.2 Research Area II – Reduce Development Costs of Existing Resources

Data Access - This area will focus on the development of a system to improve access to data collected by operators, including the compilation of E&P data into a nationwide database compatible with GIS systems and providing a means of making this data available to industry. The Canadian model, where operators are required to submit data to the government after a set period, is one approach. Applications include data mining, basin studies, defining knowledge gaps, avoiding the loss of legacy information and assuring the value associated with future work. The objectives of this work are to capture data that is currently inaccessible in company archives, desk drawers and old reports, and assure that a system is in place to make the data from future studies widely available. The workshop groups clearly recognized the need to preserve proprietary access to data to allow those that paid for the data to realize a return on their investment. Nevertheless, they felt that the industry as a whole would benefit by a means to prevent the loss of valuable data and provide appropriate collection, organization and access schemes. This was a central theme of the Golden workshop and was ranked first by that group, and tied for first place at the Pittsburgh workshop.

Reservoir Characterization – This area includes the conducting of detailed studies of specific unconventional gas resources to develop a fundamental understanding of the factors controlling reserves and production. The goal is to develop an understanding sufficient to apply knowledge to new reservoirs without extensive trial and error to develop best practices. It will be crucial to understand the effects of natural fractures, depositional and diagenetic effects and other factors that might control the distribution of reservoir properties. In addition, methods need to be developed to reliably characterize the distribution of these properties pre-drill and from well data. Success in this area will lower costs through reducing the number of marginal wells drilled and assuring that expensive data acquisition efforts are focused on truly relevant data. This topic was tied for the top ranking in the Pittsburgh workshop and was one of the top three vote collectors in the Houston session. Much of the discussion in Golden regarding the topic **Predictability of Production**, which tied for second-place rank, falls within the scope of this topic. This topic and the following one, **Production Prediction and Optimization** are closely related.

Production Prediction and Optimization – This area includes the development of the means to determine the optimum development scenario for a particular reservoir, in terms of parameters such as well spacing, well design (vertical, horizontal, multi-lateral, etc.) and completion/stimulation methods. Also included is development of the tools to predict production under these various scenarios. The goal is to build on the knowledge of reservoir properties and tie that knowledge into the actual decision-making regarding field development options. As with the **Reservoir Characterization** topic, it will be important to develop an understanding at a sufficiently fundamental level to guide field development decisions early in the development cycle, before “best practices” have been determined by trial and error. The need for these types of analysis tools is driven not only by the desire to reduce the cost of development of particular resources, but also to assure that limited





development dollars are invested in those resources that will generate the best returns in term of production. **Predictability of Production** was the second-ranked topic in the Golden workshop, and **Production Prediction and Optimization** was ranked fourth in the Pittsburgh session, receiving almost as many votes as the three topics tied for first. The discussion regarding the top-ranked **Basic Research** topic during the Houston workshop included many elements associated with this topic and **Reservoir Characterization**.

Advanced Well Construction - This area focuses on the development of improved methods to link the reservoir to the wellbore. Examples include fishbone drilling patterns, more efficient drilling in hard rocks, improved hydraulic fracturing and stimulation, methods for formation damage prevention and mitigation, and methodologies to better link engineering design of wells to reservoir characteristics. Improvements that lower the cost of existing approaches will have an immediate impact on unconventional gas production. However, innovative methods that substantially improve the efficiency of the wellbore/formation interface also have the potential to open up tight resources that are currently uneconomic. This topic was tied for second place in the Golden workshop, and related issues were discussed in Pittsburgh under the highly ranked **Stimulation** topic. These needs were also identified during the discussion of the second-ranked **Field-Based Testing** topic in Houston.

3.4.3 Research Area III - Crosscutting Topics

Environmental and Land Access – This area includes development of technological solutions or policy initiatives that improve access to prospective unconventional gas resources. Technological challenges to address include produced water handling, reducing well footprint, development with fewer wells and other initiatives that reduce the environmental impact of unconventional gas development. It is important to address the unique environmental factors impacting natural gas development in each region of the U.S. and to provide quantitative estimates of the size of the resource base restricted from development nationwide. New development approaches with sufficient environmental benefits to open up currently inaccessible resources have the potential to increase unconventional gas production in the very near term. A sustained program directed toward decreasing the environmental impact of unconventional gas development will enable the maximum production to be realized from all technological improvements that enable the development of new unconventional gas resources. This topic was of particular interest to the participants in the Golden workshop, where it ranked in the middle of the topics receiving significant votes. Despite a considerable amount of discussion regarding the unique environmental constraints of operating in the eastern U.S., the topic did not receive many votes in the Pittsburgh workshop. A discussion of environmental considerations affecting the deployment of technology for unconventional gas development is included in Section 7 of this report.

Manpower - This area focuses on the need to increase the pool of E&P expertise through support of universities, encouragement of E&P careers and other means. There was considerable discussion at the Houston and Pittsburgh workshops about





the diminishing pool of E&P expertise as many in the current workforce reach retirement age and new graduates remain hard to recruit. In both workshops, this topic appeared in the middle of the rankings. However, the degree of discussion and agreement regarding the significance of this issue warrants mention in this report. We feel that the concerns expressed in the workshops can be at least partially addressed by ensuring that universities have a role in unconventional gas research. Participation in this research can provide needed support for graduate students, as well as giving these students the opportunity to work with industrial partners and develop the skills necessary to rapidly become effective contributors to the domestic E&P industry.

Basic Research - This area includes basic research leading to a fundamental understanding of the properties of unconventional gas reservoirs, and how those properties drive optimum exploration and production approaches. The discussion of basic research was a central theme of the Houston workshop, driven by a feeling that our limited understanding of many unconventional gas resources makes it difficult to transfer knowledge and experience gained during the development of one resource to similar resources in different geographical or geologic settings. In fact, there is a sense that we often may not be pursuing the optimum development strategy for a particular resource, even if it is being economically produced. The current relationships among the producers, service industry and research providers often seem to leave gaps in the funding available for research that is not directly related to solving a problem in a specific reservoir or resource. A publicly funded research program could be expected to identify and fill in some of those gaps. As noted in the discussions of earlier topics, especially **Field-Based Testing, Reservoir Characterization**, and **Production Prediction and Optimization**, elements of basic research are an important part of the needs associated with these topics. At the Golden workshop, participants voted that an average of 20% of research funds should be devoted to Basic Research.





4. Summary of Technology Needs Identified from the Workshops

The study by the NPC (NPC, 2003) outlines several key findings that may help define the research needs for Unconventional Gas resources:

1. *Technology improvements will play a key role in increasing natural gas supply*
2. *Adding new North American natural gas supplies will require finding, developing and producing more technologically challenging resources*
3. *Investments in research, development and application of new technology have declined over the last 10 years*
4. *The gas exploration and production industry should collaborate more effectively with the Department of Energy in the planning and execution of complementary, not competitive, research and development programs*
5. *Environmental and safety concerns are significant drivers in the development and application of new technologies*
6. *Professional workforce demographics -- age, diversity, competency, and experience -- will need to be effectively managed*

The first four findings are well aligned with the input from workshop participants. The final two findings are points that were discussed at length during the workshops, but were not competitive with specific technology areas when input regarding priorities for research investment was collected.

In Section 3.4, the high-priority research topics derived from the recent workshops are classified into three general groupings, as specified below.

Research Area I Development and Characterization of New Resources	<ul style="list-style-type: none"> • Resource Assessment • Basin-Scale Petroleum Systems Studies • Field-Based Testing
Research Area II Reduced Development Costs of Existing Resources	<ul style="list-style-type: none"> • Data Access • Reservoir Characterization • Production Prediction and Optimization • Advanced Well Construction
Research Area III Crosscutting Topics	<ul style="list-style-type: none"> • Basic Research • Environmental and Land Access • Manpower

A detailed description of each of these topics is included in Section 3.4. It is worth noting for comparison with the New Mexico Tech workshop that all of the specific unconventional gas R&D needs described in Table 11 (Section 5.2) as Top Priority in one or more regions fit clearly within one of the above categories.





The Research Area I topics represent activities that are necessary if substantial new unconventional gas resources are to be identified and developed sufficiently to meet the anticipated demand for unconventional gas. While the impact of these activities is not immediate, they are essential if the anticipated contribution of unconventional gas to the U.S. resource base is to be realized.

Research Area II includes topics that will assist operators in increasing production in the near term. These topics are aimed toward problems that producers are currently experiencing and for which solutions will find a ready market. Much of the discussion in the workshops (see Section 3) was focused on topics within this group.

Finally, Research Area III addresses issues that cut across all areas of unconventional gas development. While **Basic Research** received considerable support both directly and as an element of other topics, **Manpower** and **Environmental and Land Access** were given a lower priority. Nevertheless, there was considerable discussion on these last two topics, and their alignment with the Findings of the 2003 NPC study reinforces their importance. Key focus areas are described below.

4.1 Identification and Development of New Resources

In order to ensure development of all potential gas resources, it is important to initiate a basin-by-basin study of all possible unconventional gas accumulations.

Clearly, such an assessment must build on past efforts by USGS, PGC and others. In basins with a long history of oil and gas production, there will be much data and likely few surprises. However, there may be unconventional gas opportunities in basins that have not been the object of conventional oil and gas exploration and development, and the possibilities of resource accumulations in these new areas should be evaluated. Such evaluation will require geologic and petroleum systems studies, using whatever data is available or that can be collected at a reasonable cost.

There will be a continuum from the assessment of frontier basins to the assessment of new unconventional resources in mature basins. The challenge will be to allocate limited research funds to define these opportunities in a way that maximizes the probability of uncovering significant new resources.

As sufficiently promising opportunities are developed, it will be important to partner with interested operators to drill test wells and further define the nature of potential new resources and the appropriate approaches to production.

4.2 Lower the Cost of Unconventional Gas Development

The bulk of the discussion in the workshop sessions focused on better ways to develop unconventional gas resources. There was frustration about the frequent inability to properly characterize the reservoir properties that control production and to determine the most efficient development approach. There was uncertainty on the selection and execution of the best well construction, completion and stimulation methods. Finally, our industry lacks an organized approach to preserving valuable data that could reduce the cost of entering a new area or evaluating a new resource.





We might approach these challenges by selecting the technologies that are likely to have the most potential for addressing the issues associated with particular resources. Controlled experiments may then provide the opportunity for developing an understanding of the application of these technologies. The goal is for that understanding to be sufficiently fundamental to allow the effective use of studied technologies in formations and settings that may differ substantially from those in which the original experiments were performed. Field experiments may often be performed in conjunction with commercial wells.

4.3 Manpower

As a large portion of the current workforce in the E&P industry reaches retirement age, the availability of trained and educated staff will affect the impact of any new unconventional gas technology. Active participation by universities in the development of unconventional gas technology will provide opportunities for students to be exposed to the opportunities in oil and gas development, and develop the necessary skills to contribute to the industry.

4.4 Environmental and Land Access

The development of new unconventional gas resources is taking place in an era of increased environmental awareness and concern. While natural gas is generally (and correctly) perceived to be the cleanest of the fossil fuels, the steps associated with the exploration for and production of unconventional gas resources impacts the land in ways that must be understood and minimized. Environmental concerns range from factors such as the potential impact of drilling operations on tourism in portions of the eastern U.S. to concerns about management of produced water and the “footprint” of drilling and production sites. Efforts to actively address these concerns may open new areas to unconventional gas development and allow more extensive development of existing resources. The most immediate impact on gas production in the U.S. could probably be achieved by opening up areas now closed to exploration and production within which there are known resources. Reducing the environmental footprint of unconventional gas E&P operations may be the most likely way to gain access to these resources.

In most areas of unconventional gas technology, the producers will be very aware of the technological challenges and opportunities. They will thus be in a position to provide significant direction to unconventional gas technology development. In the environmental area, producers are less likely to be familiar with the opportunities associated with potential technology advances. Appendix B of this report provides more complete discussion of environmental considerations affecting unconventional gas technology, along with some ideas of how an environmental program may be shaped to impact access to resources.





5. Past Studies Relevant to Unconventional Gas Technology

5.1 National Petroleum Council Study and Workshops

The National Petroleum Council (NPC, 2003) conducted a comprehensive study on the status, future direction, and needs of the U.S. natural gas industry. A Technology Subgroup, with representation from the oil and gas industry, assessed the role and impact of technology on natural gas supply in North America. Several workshops were convened to provide a forum for industry experts to discuss the role of technology in sustaining the supply of natural gas. Unconventional gas was an important component of the study. The NPC identified six key findings and recommendations:

Technology's role for improved production is especially evident in non-conventional reservoirs such as coalbed methane, shale gas and tight sand formations.

Technology improvements will play an important role in increasing natural gas supply.

During the last decade, 3D-seismic analysis, horizontal drilling, and improved fracture stimulation have enhanced natural gas production in many North American basins. In addition to these step-change technologies, ongoing improvements in core technologies have been implemented through the industry's continuing efforts to search for cost-effective ways to find, develop and operate oil and gas fields. This trend is especially evident in the production of non-conventional gas reservoirs such as coal bed methane, shale gas and tight sand formations.

Adding new North American natural gas supplies will require finding, developing and producing more technologically challenging resources than ever before.

As more unconventional gas resources are developed, the average permeability of the producing reservoirs will continue to decrease, requiring the industry to find and apply new technologies.

New natural gas resources that will be developed over the next 25 years will generally be deeper, hotter, tighter, more remote, smaller, harder-to-find, and/or in deeper water than current resources. These attributes will require industry and government to develop and apply new and improved technologies to produce these resources.

As unconventional gas resources are developed, average reservoir yields will decrease, requiring the industry to develop and apply new technologies or best practices that enable low permeability wells to produce at economic flow rates. The industry will be challenged to develop methods to locate "sweet spots" in tight basin-centered gas fields, shale gas and coal bed methane reservoirs, reducing the number of marginally commercial wells being completed.

R&D investments and use of new technology have declined over the last 10 years.

Although there is no definitive information on oil and gas industry spending on technology improvements focused on North America natural gas assets, over the last decade the trend in upstream research and development spending has been downward, as reported by the U.S. major energy producers through the EIA (EIA, 2005).





The Research and Development effort role of researching and developing new technologies has been shifting away from major oil and gas companies doing proprietary research to the service industries and joint-sponsored research programs. This can be viewed as a cost-effective and less redundant method of research. It may also have the effect of slowing down the application of new technologies due to limited field test opportunities. There is also the issue that service company R&D investments must follow the near-term needs of their largest customers, while non-majors undertake much of the unconventional gas development in the U.S.

The gas exploration and production industry should collaborate more effectively with the Department of Energy in the planning and execution of complementary, not competitive, research and development programs.

The Department of Energy plays an important role in facilitating and sponsoring joint research and development programs within the natural gas supply industry. With the new insights developed from this study, the Department of Energy should address the question of whether the current funding level for natural gas research is appropriate relative to other R&D programs in view of the increasing challenges facing new natural gas resources within the United States.

Environmental and safety concerns are significant drivers in the development and application of new technologies.

The oil and gas industry continues to focus significant technology development efforts on environmental concerns and reducing potential safety issues in the field. As the industry and government regulatory agencies search for acceptable methods to access new areas and reduce the cost of compliance with environmental and safety regulations, these advances in technologies may enable balanced solutions.

Professional workforce demographics -- age, diversity, competency, and experience -- will need to be effectively managed.

Recommended actions to address the workforce issue include:

- Increased efforts to educate the public and promote the oil and gas industry, and to attract science and engineering students to energy careers
- Incorporation of integrated information technologies, knowledge based systems, simulators and visualization techniques to enhance the transfer of knowledge and experience from the “departing crew” to the “new crew,” and
- Taking advantage of the advanced computer skills of the next generation to accelerate acceptance of real time digital technology and data integration to enhance gas field performance and economics

5.1.1 National Petroleum Council Workshops

As noted above, the NPC conducted a series of workshops with industry. At each workshop, technology areas and needs were identified. The results of these workshops have been reviewed for their relevancy and application to unconventional gas resources. The workshop topics included:





- Coalbed Methane
- Drilling Technology
- Well Completion Technology
- Subsurface Imaging Technology

Results from the NPC Workshops are discussed below.

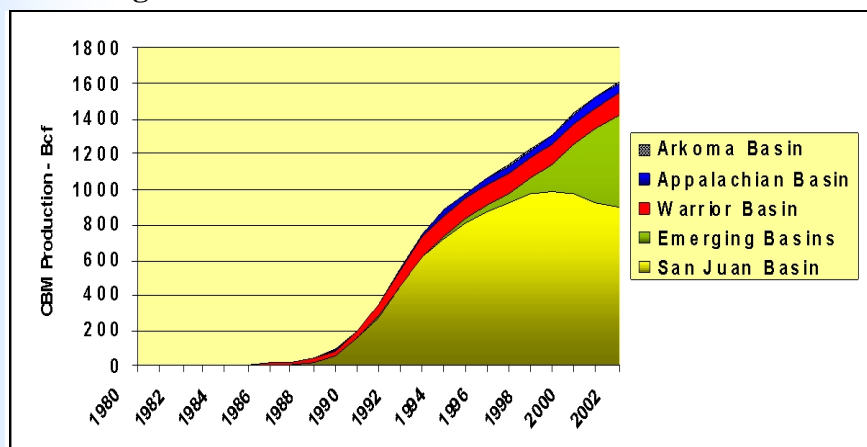
5.1.2 NPC Workshop Results

5.1.2.1 Lessons Learned from Coalbed Methane Development

Coalbed Methane is perhaps one of the best examples of how technology can have an impact on the understanding and eventual development of a natural gas resource. As the only NPC workshop addressing a specific unconventional gas resource, the Coalbed Methane workshop served as a surrogate for a discussion of the potential impact of technology on production from other unconventional gas resources. For this reason, we will discuss the results of the Coalbed Methane workshop in some detail.

While gas has been known to exist in coal seams for many years, only since 1989 has significant gas production been realized (Figure 12).

Figure 12 - U.S. Gas Production from Coal Seams



Coalbed Methane (CBM) is a resource that was known for many years yet never produced. CBM-focused research and new technology ultimately unlocked the production potential. Coalbed Methane now provides over 1.5 tcf of U.S. gas production per year. This was accomplished through concerted efforts to assess the resource and

understand the many reservoir properties controlling production. New well construction procedures allowing economic well completions were also developed, representing critical components of CBM technology.

Status of Coalbed Methane Technology

Coalbed Methane production behavior is similar to the conventional gas resource in many respects, yet differs in several important areas. One prominent difference is in the understanding of the resource with regard to gas-in-place. Natural gas in coal seams adsorbs to the coal surface, allowing significantly more gas to be stored than in conventional rocks. CBM production also requires a substantial pressure drop to release the adsorbed gas. This phenomenon was not important for conventional gas resources and required research and new technology to fully understand the principles and realize the production potential. A third major difference is the presence of large





volumes of water requiring removal prior to significant gas production. Technology for understanding and dewatering the coal seams paved the way for significant CBM development in several U.S. geologic basins. On the other hand, several aspects of conventional well construction were readily adapted to CBM operations (primarily the drilling process). Table 7 identifies several of the most important CBM technology areas and describes the sources of the current technology or practice.

Table 7 - Technologies Important For Past Development of CBM Resources

Technology Area	Source of Current Technology
Adsorption/Desorption of Gas on Coal	R&D on coalbed methane adsorption/desorption processes
Well Drilling	Application of existing industry practices
Coal Cleats and Cleat Systems	R&D on impact of cleat systems on production
Gas-In-Place	R&D on adsorption for coal types, age and properties
Well Stimulation	Industry hydraulic fracturing techniques applied but modified for coal seams based on R&D efforts

Future CBM Technology Requirements

In order to determine the potential and need for CBM technology in the future, the NPC conducted a workshop with industry experts to identify technology needs and quantify technology change over the next 25 years. Six major areas were identified as important for future CBM development (Table 8).

Table 8 - Major Areas for Future CBM Technology Improvements

Technology Area	Technology Need
Multi-Zone Well Completion	Technology for construction of fishbone well patterns and directional control within thin coal formations
Smaller Well Footprint	Ability to drill and produce CBM wells on small surface locations. Technology allowing greater well spacing
Rapid Technology Transfer	Best Field Practices will need to be rapidly disseminated amongst operators
Produced Water Technology	Technology and understanding of issues changing Produced Water from waste to resource
Improved Gas Recovery per Well	More effective well stimulation techniques and new technologies are required to maintain gas recovery
Technology Integration/Development Planning	A systematic approach to developing a CBM field integrating all technology needs development

CBM operators in general felt that CBM technology would continue to develop at a significant pace, and that technology from other oil and gas disciplines (i.e., well drilling, gas production) would continue to be adapted by CBM operators. In particular, the potential for future development in Western Canada and additional U.S. basins is thought to be significant because of the better resource understanding and applications of new CBM technology.





CBM Produced Water

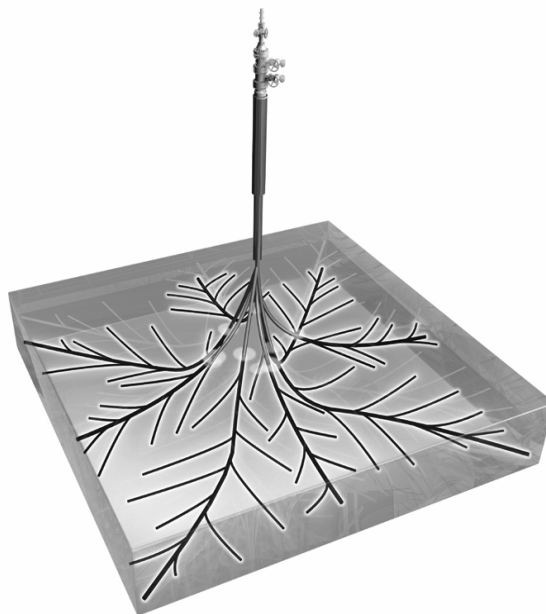
One of the most important areas for CBM technology development is in dealing with the challenge of produced water. Given the significant volume of water produced during and prior to gas production from coal seams, the significant cost thereof, and the impact and controversy surrounding removal of the water from potentially useful aquifers, it is paramount that industry develops a better and thorough understanding of CBM water management. A new approach to the CBM water issue and a complementary portfolio of new technology for water handling will be required. The contemporary practice of “produce and dispose” will need to be supplanted with new approaches including down hole disposal, beneficial use of water in arid climates, re-injection into potable aquifers for recharge and other yet-to-be-developed procedures. All of these practices will be enabled through new technology development.

CBM Improved Recovery Per Well

Coal seams, and in particular many of the remaining lower quality seams within North American geologic basins, will be thin and multiple in number, interspersed by shales and other non-productive formations. Strategies and technologies for recovery of gas from multiple (thin) coal seams will need development. Recently, there has been significant technical progress in the area of multi-lateral wellbore technology, where many wellbores emanate from a single vertical well (Figure 13). Utilizing this concept, multiple seams can be contacted and produced from a single surface location. While progress has been made in this area, significant improvements are required. In particular, the ability to drill into a relatively thin coal seam and stay within the seam will require new sensors and real-time transmission of data to allow constant and accurate knowledge of bit location. Additionally, the ability to respond and achieve real-time steering with greater precision will be needed.

The overall impact of this technology will be to maintain or increase the volume of gas produced from a single well despite the lower quality coal seams from which the gas is produced. Well costs could increase due to greater multilateral drilling activity, but this will be more than offset by increased gas recovery. Of significance will be the reduced surface footprint. Other technologies, such as well stimulation procedures and more effective cavity completions, will also require further refinement and development.

Figure 13 - Multilateral Well Schematic





5.1.2.2 Drilling, Well Completion and Subsurface Imaging Technologies

To determine the challenges and technology needs in the areas of Well Drilling, Completion and Subsurface Imaging, the NPC Technology Subgroup conducted special sessions with industry experts to identify technology needs and quantify technology change over the next 25 years. Tables 9, 10 and 11 identify the technology needs for Drilling, Well Completion and Subsurface Imaging respectively.

Table 9 - Drilling Technologies

Technology Area	Technology Needs
Rig designs to reduce “flat-time”, and provide safer, environmentally-friendly operations	<ul style="list-style-type: none"> • Small modular rigs with state-of-the-art pump equipment, automated pipe handling, and control systems. • Casing drilling, coiled tubing drilling • Environmentally-friendly drilling fluids • Multi-lateral with long-reach horizontal configurations to reduce number of surface locations
Deeper, high temperature/high pressure wells	<ul style="list-style-type: none"> • Develop drilling equipment and electronic sensors that can withstand the high temperature and pressure regimes • Expandable pipe to reduce weight and number of casing strings • Micro technologies to reduce equipment size and allow smaller diameter wells
Deep wells drilled in deep water	<ul style="list-style-type: none"> • Expandable casing • Light-weight composite pipe • Dual gradient fluid systems • Smaller rigs capable of drilling in deeper water at greater depths
Low recovery wells	<ul style="list-style-type: none"> • Multi-lateral to increase effective drainage • More durable, high penetration rate drill bits for hard rock • Laser drilling
High cost exploration wells	<ul style="list-style-type: none"> • Micro technologies to reduce well-bore diameter requirements • Down-hole sensors for real-time measurements while drilling and steerable drilling

Table 10 - Well Completion Technologies

Technology Area	Technology Needs
Improved recovery efficiency	<ul style="list-style-type: none"> • Improved stimulation technologies for higher initial production and more effective drainage • Multi-lateral and multi-zone completion technologies to maximize recoveries with fewer wells • Real time bottom-hole measurements to monitor well and reservoir performance • Improved perforating technologies





Technology Area	Technology Needs
	<ul style="list-style-type: none"> Down-hole controls to prevent water influx Down-hole fluid separation/injection and compression and power generation to maximize well performance
Deeper, high temperature/high pressure wells	<ul style="list-style-type: none"> Completion equipment and electronic sensors that can withstand the high temperature and pressure regimes Expandable pipe to reduce allow for larger bottom-hole production equipment without adding number of casing strings High temperature drilling and frac fluids
Tight sands	<ul style="list-style-type: none"> Improved fracture stimulation
Low recovery wells from small pools, thin sands, low porosity	<ul style="list-style-type: none"> Technologies focused on reducing cost per mcf Bottom-hole compression to increase production of low pressure reservoirs Multi-lateral, steerable, extended reach wells to maximize reservoir wellbore exposure to the reservoir

Table 11 - Subsurface Imaging Technologies

Technology Area	Technology Needs
Seismic data acquisition and resolution	<ul style="list-style-type: none"> Lower cost, less destructive methods of acquiring seismic data Further advances in data management to reduce costs Ability to obtain seismic data while drilling Single sensor recording to improve data resolution and accuracy
Interpretation	<ul style="list-style-type: none"> Further enhancements in pre-stack depth migration to enhance the seismic images Increased computational technologies to apply advance interpretation methods Multi-component imaging to identify reservoir fluid properties Method to identify “sweet spots” in unconventional gas plays
Reservoir monitoring	<ul style="list-style-type: none"> Further enhancement of 4D technology to find undepleted areas of the reservoir Permanent sensors for real-time measuring and reservoir monitoring
Integration with other technologies	<ul style="list-style-type: none"> Ability to quickly integrate seismic information with earth and reservoir models to provide quick visual images to multi-disciplined teams for better decision-making approaches Advanced visualization technologies to better understand the reservoir and create the digital gas field of the future





5.1.2.3 Other Technology Challenges Identified by the NPC study

Multiple challenges will face the North American petroleum industry and government as they pursue research, development and application of new technologies to enhance the supply of natural gas. Many of the North American producing basins are maturing, but significant technically recoverable resources still remain. However, the declining reserves and economics make it harder to justify major investments in new technology. Independent companies, which will play an increasing role in these mature basins, will have to increasingly collaborate with the service industry to support the required technology development. Industry must also speed up acceptance and utilization of the new technologies. Having many competing producers spread across North America creates a challenge to efficient and effective technology collaboration. Professional societies, trade associations, academic and government research institutions, along with the industry, will need to increase efforts to communicate and work together to deploy new applications.

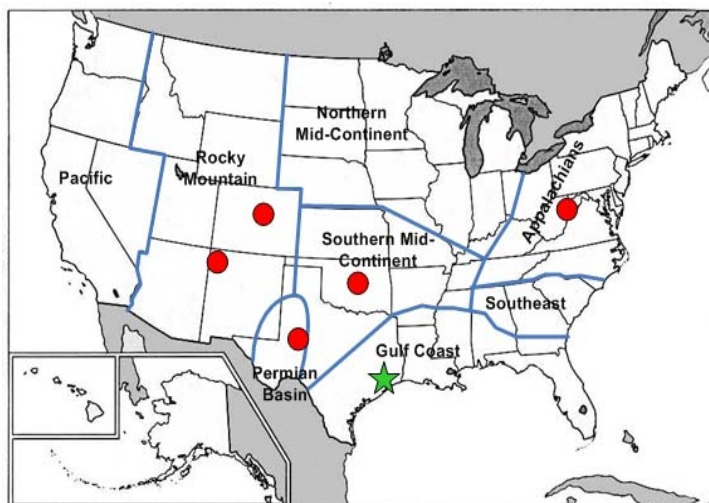
Another challenge will be to effectively transfer the knowledge and experience of the existing professional workforce to the new generation entering the industry and research institutions. Otherwise, the risk of “reinventing the wheel” will loom over the industry. With the expected tight supplies of natural gas, potentially higher prices, and ever-increasing technical challenges, the petroleum industry, research institutions and governments need to put in place strategic plans to respond to these challenges.

5.2 New Mexico Tech Workshops on Unconventional Gas

New Mexico Tech (NMT) facilitated a series of regional focus group meetings to define the technology problems facing industry and to help establish recommendations for defining specific short and long-term research & development needs in exploration for and production of unconventional gas resources (Engler, et. al., 2003). The locations of these meetings are shown in Figure 14 and were selected as representative of the major unconventional gas basins of the country.

Invited participants represented diverse backgrounds, including producers and service companies, academia, and federal and state agencies. Approximately 25 participants attended each of the five workshops. The largest segment of the participants (39%) was from the independent producer sector of the industry.

Figure 14 - Location of NMT regional focus group meetings - Summer 2002





5.2.1 Technology Needs by Region

The information collected was integrated to establish a set of technology needs. Dominant themes emerged in the categories such as stimulation, natural fracture characterization and data warehousing. Results were organized by region, by technology group, and by geologic play. Survey and workshop results were then combined to develop a comprehensive list of technology needs by region (Table 12). Items indicated with ① in the table are those technologies that were given the highest priority in either a regional meeting or the survey, or were consistently ranked important in several venues. Lack of a symbol does not mean the technology is of no importance, but rather was not designated as a priority or interest at this time.

Table 12 - Summary of Unconventional Gas R&D Needs from the New Mexico Tech Focus Group Meetings

Topic	San Juan	Permian	Oklahoma	West VA	Rocky Mt.
Reservoir characterization, imaging	•	•	①	①	①
Stimulation	•	①	①		
Play-based resource assessment		•		①	•
Data mining, data collection			①	①	
Producibility models			①		
Handling, treating and disposal of produced water	①				
Extending well life				①	
Advanced drilling technologies, drilling cost reduction	•			•	
Horizontal well completion strategy		•			
Expert systems		•			
Processing of low-BTU gas		•			
Liquid removal from deep gas wells		•			
Core drilling/evaluation				•	
Production performance monitoring and evaluation					•

① = Top Priority

5.2.2 New Mexico Tech Study Conclusions

The United States has abundant natural gas resources available to meet the future growth in energy demand. However, to increase the deliverability of existing plays and basins or to explore in emerging plays and basins will require investment in science and technology. A strategy to achieve this goal is to implement the priority mechanisms listed above. Collaborative research efforts between government and industry in the past decade have yielded unconventional gas production increases of 1 to 4 tcf per year. Meeting future challenges will require continued innovation. The potential benefits are reduced dependency on imported energy and wider use of a clean, efficient and environmentally friendly energy source.





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We would like to thank Dr. Dan Lopez, Dr. Steve Holditch, and Dr. Tom Engler for their time and efforts. Each made important contributions to the workshops with their presentations.

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Appendix A - Workshop Attendees

Workshop - Houston Texas - July 19, 2005	
Company Affiliation	Participant Name(s)
Alpine, Inc.	Brenda Claxton
Anadarko	Wayne Camp
Baker Atlas	Dan Georgi
BP	Richard Keck
CDX - Gas LLC	Chuck Edwards
DOE/NETL	Jim Ammer
Duke Energy Field Services, LP	Darrell Pierce
El Paso Production Company	Steve McKetta
Gas Technology Institute	Kent Perry,
Gas Technology Institute	Robert Siegfried
Gas Technology Institute	Iraj Salehi
Gas Technology Institute	Brian Weeks
Halliburton	Jacob Thomas
Halliburton/Landmark	Charlene Burman
Los Alamos National Lab	Lianjie Huang
Marathon Oil	Paul Gardner
New Mexico Institute of Mining and Technology	Dan Lopez, Thomas Engler, Van Romero
Nicor Gas	Mike Fugate
Pitts Oil Company	David Martineau
Rosewood Resources	Mark Malinowsky
RPSEA	Steve Beach
SAIC	Charles Thomas
Schlumberger - DCS	Valerie Jochen
University of Texas at Austin	Mukul Sharma
Vecta Exploration	Allen Gilmer

Workshop - Golden Colorado - August 9, 2005	
Company Affiliation	Participant Name(s)
Baker Atlas	Roger Reinmiller
Barlow & Haun	Mark Doelger
CDX-Gas	Chuck Edwards
CERI	Dag Nummedal
CERI	Geoffrey Thyne
CERI	Jim Bryant
CSM/CERI	John Curtis
DOE	Gary Covatch
Forest Oil	Roger Wiggin
Gas Technology Institute	Kent Perry, Robert Siegfried
Halliburton	Mike Eberhard
Independent	Jim Emme
K. Stewart Energy	Mike Ming
Kerr-McGee	Kurt Reisser, Steve Sonnenberg





Workshop - Golden Colorado - August 9, 2005	
Company Affiliation	Participant Name(s)
MGV Energy	Michael Gatens
New Mexico Tech	Tom Engler
Performance Sciences	Jim Crafton
PTAC	Len Flint
RPSEA	Steve Beach
Schlumberger	Tom Olsen
Texas A&M University	Steve Holditch
XTO Energy	Lance Cook

Workshop - Pittsburgh PA - August 25, 2005	
Company Affiliation	Participant Name(s)
Baker Hughes	Bill Rubin
DOE	Jim Ammer
EnerVest Operating	James Ayers, Kevin Miller
Gas Technology Institute	Kent Perry, Robert Siegfried
Linn Energy LLC	Gerry Merriam
New Mexico Tech	Tom Engler
NYSERDA	John Martin
Ohio Geological Survey	Ernie Slucher
Pennsylvania Geological Survey	Toni Markowski
RPSEA	Steve Beach
SAIC (NETL/DOE)	Ken Kern
Schlumberger	Larry Pekot
U.S. Geological Survey	Bob Milici
West Virginia Geological Survey	Doug Patchen





Appendix B - Environmental Considerations Affecting Unconventional Gas Technology Deployment

The natural gas industry is well aware that the pursuit of new production capacity through the further development of unconventional gas technologies must be accomplished in a manner that complies with all applicable Federal, State, and Local laws regarding the protection of human health and the environment. In particular, environmental agencies and regulations can overwhelmingly retard the pace at which

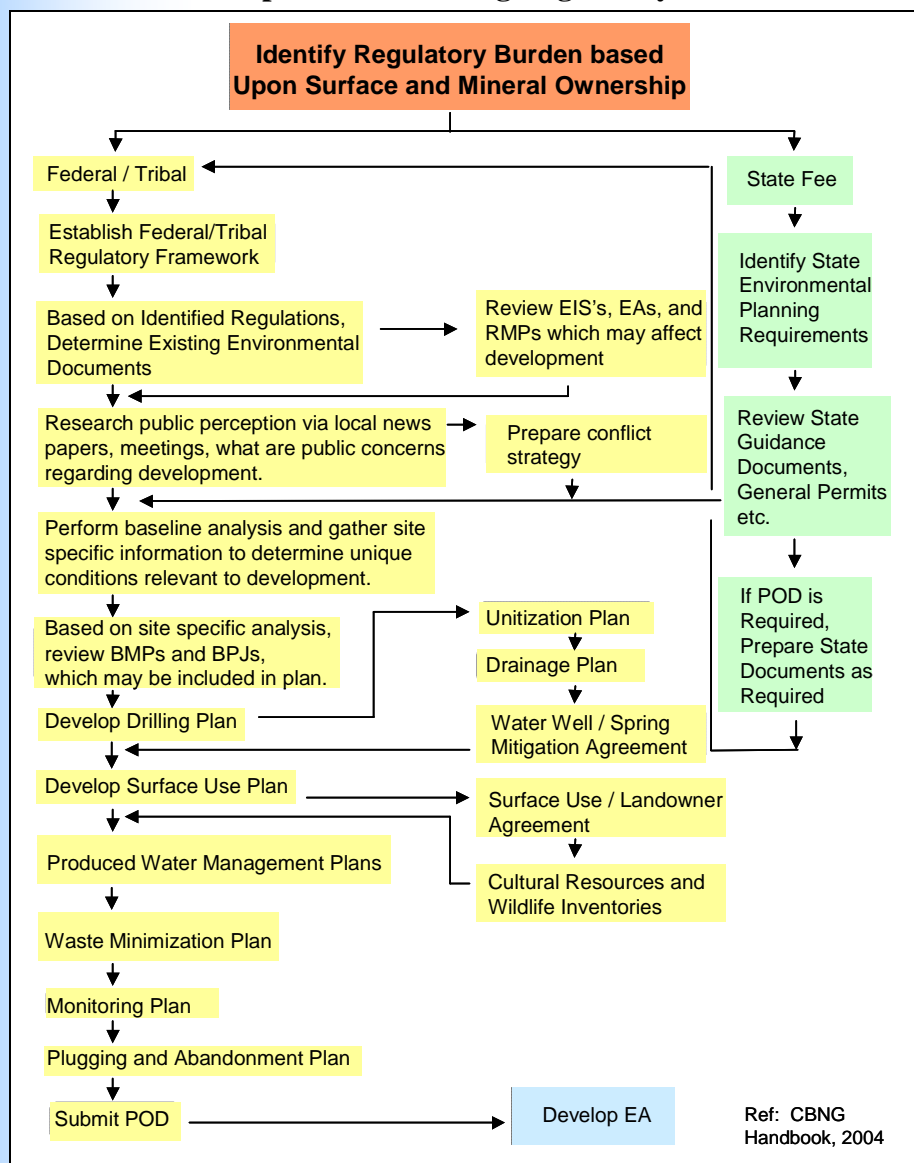
unconventional natural gas is developed in the U.S.

Demonstrating environmental compatibility and compliance is key to gaining access to lands and stakeholder cooperation that is critical to unconventional gas technology deployment.

The National Petroleum Council has raised this area as a priority concern and has urged that procedures be developed to expedite permitting (NPC, 2003).

State and Federal agencies are involved in the environmental permitting of drilling and production operations in many areas where unconventional gas would be expanded. Often, serious delays can be caused from a lack of information concerning the volumes and characteristics of wastes that are likely to be generated in the deployment of unconventional gas technologies. This has been the case in the implementation of coal bed natural gas (CBNG) in a number of basins in the

Figure B1 - Complexity Involved in CBNG Plan of Development Addressing Regulatory Needs



Rocky Mountain region over the past decade, contributing to a high level of complexity of CBNG planning required to respond to a time-consuming system of permitting as shown in the diagram of Figure B1.





Certainly, there is much improvement that can be made in streamlining the permitting process for unconventional gas implementation.

It is expected that nearly all areas of on-shore unconventional natural gas production

will involve many of the basic categories of wellhead operations used in conventional gas development and production described by Fillo and Mesing, 1997.

Flow schemes for exploration and well construction and wellhead production are provided in Figures B2 and B3, respectively.

Figure B2 - Drilling and Well Construction Waste Streams

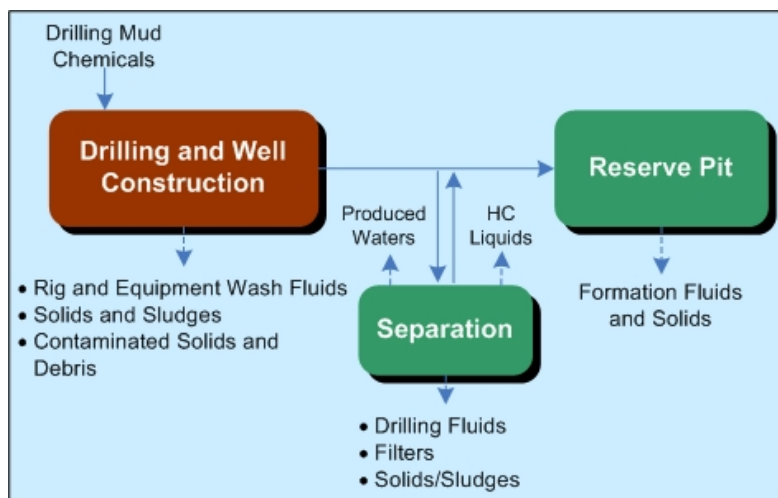
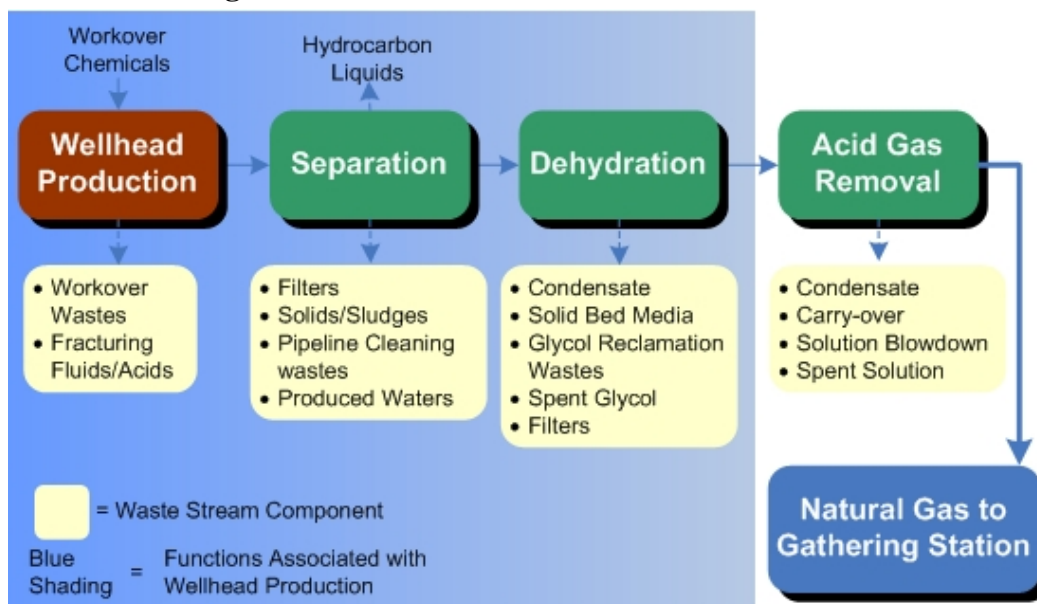


Figure B3 - Wellhead Production Waste Streams





Lists of wastes, chemicals of interest, and environmental issues associated with these operations are given in Table B1

Table B1 - Lists of Wastes, Chemicals of Interest and Environmental Issues

Wastes from Exploration and Well Construction	Wastes from Wellhead Production Operations	Chemicals of Regulatory Interest	Potential Environmental Impacts
<ul style="list-style-type: none"> • Formation Fluids and Solids • Drill Cuttings • Contaminated Solids and Debris • Equipment Wash Fluids • Produced Waters • Hydrocarbon Liquids • Solids and Sludges • Expended Filters • Drilling Fluids 	<ul style="list-style-type: none"> • Workover Wastes • Hydrocarbon Liquids • Produced Waters • Hydrocarbon Liquids • Sludges and Solids • Expended Filters • Pipeline Cleaning Wastes • Spent Glycol • Dehydration Waters • Solid Bed Media • Glycol Reclamation Wastes • Glycol Fluid Spillage 	<ul style="list-style-type: none"> • Total Petroleum Hydrocarbon • Monoaromatic Hydrocarbons (e.g., benzene, toluene, etc.) • Polynuclear Aromatic Hydrocarbons • Residuals of Chemicals Used in Drilling and Well Operations (caustics, acids, stabilizers, etc.) • Glycol • Biocides • Corrosion Inhibitors • Metals (zinc, lead, iron, etc.) • Naturally Occurring Radioactive Materials (NORM) 	<ul style="list-style-type: none"> • Contaminant releases to soils • Groundwater impacts • Produced water discharges to surface waters • Wildlife • Noise • Air impacts • Worker Safety

These considerations are important because they can potentially raise concerns over the environmental impact of new technologies and ultimately cause considerable delays in the governmental permitting processes and in gaining access to federal and private lands for development. In the eventual deployment of most unconventional natural gas technologies, federal and state laws will likely affect the pace of permitting and implementation. Some of the major laws and regulations and their applicability to the elements of unconventional gas production are shown in Table B2.





Table B2 - Major Laws and Regulations that will affect Unconventional Gas Development and Production

Laws and Regulations	--- Direct Applicability ---				
	Citing and Planning	Drilling and Completion	Stimulation & Maintenance	Operations	Worker Safety
Mineral Leasing Act of 1920	X			X	
Natural Environmental Policy Act (NEPA)	X	X			X
Clean Air Act		X	X	X	
Clean Water Act	X	X	X	X	
Toxic Substances Control Act (TSCA)		X	X		X
Resource Conservation and Recovery Act (RCRA)		X	X	X	X
Occupational Safety and Health Act		X	X	X	X
Endangered Species Act of 1973	X	X		X	
Antiquities Act of 1906	X	X			
National Historic Preservation Act of 1966	X	X			
Forest Rangeland Renewable Resources Act	X	X			
Federal Land Policy and Management Act	X	X			
Emergency Planning and Community Right to Know Act	X	X			
Pollution Prevention Act	X	X			
State and Local Permits	X	X		X	X

Environmental permitting delays are largely caused by uncertainties associated with a lack of information on waste generation. Although the waste streams and chemicals of concern shown in Table B1 relate to conventional gas production, processes involved in unconventional gas E&P operations will potentially generate some of the same types of waste, plus other constituents that may be of interest to environmental regulators. In other words, the development of new unconventional gas methods and technologies will undoubtedly lead to uncertainties concerning the volumes and nature of the waste streams that will be generated. Information gaps related to these waste streams and the methods required to effectively manage them need to be addressed as a part of the technology development effort to avoid substantial permitting delays and to facilitate commercial deployment.

Environmentally Acceptable Operations to Gain Access to Lands for Unconventional Gas Development

Since the federal, state and local regulatory processes affect the pace of deployment of new unconventional technologies, there is a need for technology that leads to cost effective compliance and streamlining of the permitting processes.

In most cases, new on-shore unconventional gas developments will occur in remote





areas that can be characterized as mostly rural and arid in nature. Land uses will include ranching, residential, outdoor recreation, vacation homes and retirement locations. If significant volumes of produced waters can be potentially generated from an unconventional gas development effort, there may be substantial interest among numerous stakeholders in how the water is managed and its potential for beneficial use. Although operations will not be proximal to dense population centers, future planning will need to consider potential impacts to water, air quality, land use, socioeconomic state of the community, and water resource allocations.

In this setting, unconventional gas development needs to be prepared to encounter a permit system at the federal, state and local levels that is more established and mature than encountered in the Western States three decades ago. The regulatory acceptance of new unconventional gas technologies can be significantly facilitated by the development of quality data and information required by the permit systems. The sophistication of the permit programs for a number of federal and state agencies has improved markedly to the extent that new modeling techniques, characterization methods, analytical techniques, risk analysis methods and database management approaches have been evaluated and adopted by these organizations on an ongoing basis. Significantly, environmental organizations are increasingly sharing information to assist in their decision-making. In this emerging relationship, consensus and reasonable decisions arise from adequate data and good science that underpin proposed developments. A good portion of this information needs to be generated during the development of unconventional gas technologies; it is suggested that a complete roadmap of R&D include elements that will provide a body of technical information that responds to a mature, well-defined permit system and expedites environmental compliance at the lowest cost.

Environmental Elements Impacting Unconventional Gas Technology Development Needs

In the course of developing each type of unconventional gas technology to improve the accessibility of natural gas reserves and the economics of production, there are a number of environmental elements that can be concomitantly addressed through an R&D program. Recommended Environmental R&D areas are described in Table B3. These R&D areas are the key to gaining stakeholder acceptance and land access critical to unconventional gas technology deployments.





Table B3 - Environmental R&D Associated with Unconventional Gas Technology Development and Improved Land Access.

Recommendation	R&D Elements	Benefit
Obtain early data on the nature of wastes and produced water.	<ul style="list-style-type: none"> • Characterize residues from the test wells used for technology development. • Include large prototype wells and early commercial wells from all basins • Obtain data on drill cuttings, production fluids, muds, produced water, and chemicals of interest 	<ul style="list-style-type: none"> • This information, along with proposed best management practices can provide the basis for estimating the potential environmental impacts and how those impacts can be minimized in the course of well construction and production.
Emphasize R&D aimed at waste minimization.	<ul style="list-style-type: none"> • Microhole and slimhole technology development to reduce wastes from drilling. • Develop new engineering design strategies for well completion and operations that minimize wastes. • Redesign composition and mass flows of chemical inputs to reduce environmental impact • Identify “green” chemicals for construction and operation of unconventional gas wells --- including environmentally friendly carrier fluids, solvents, degreasers and cleaning agents. 	<ul style="list-style-type: none"> • Reduced waste volumes and costs. • Practical waste management axiom: “If you don’t produce it --- you don’t have to treat and dispose of it.” • Improved regulatory acceptance. Federal and State Regulatory Agencies continue to emphasize waste minimization strategies for improving environmental protection.
Develop a shared information base that streamlines permitting.	<ul style="list-style-type: none"> • Develop a geographic information system (GIS) to facilitate EA and EIS studies for planning and permitting of unconventional gas develops in large areas of a basin. • Quality control and standardized protocols need to be developed to allow government agencies (such as BLM) to coordinate information sharing. 	<ul style="list-style-type: none"> • Information sharing enhances the pace of environmental decision-making. • A rapid-access, integrated environmental data management system would enable industry, stakeholders, and regulatory agencies to work together to expedite unconventional gas well field developments and new technology deployment.





Recommendation	R&D Elements	Benefit
Conduct R&D to further reduce environmental impacts.	<ul style="list-style-type: none"> Continue to make design improvements to reduce the footprint of unconventional gas technologies, especially in the Rocky Mountain Region. Examples include microhole drilling (MHD) technology and zero-discharge mud and waste management systems. Develop designs that reduce or eliminate open waste impoundments. 	<ul style="list-style-type: none"> Reduced footprint lessens the biota impact of E&P activities The shrinkage or elimination of open waste impoundments can minimize bird and animal mortality, thereby reducing natural resource damage New approaches to reduce pipe-handling safety hazards (as with MHD technologies) can also increase drilling rates as well as shorten downtime.
Develop beneficial-use technologies for produced water management.	<ul style="list-style-type: none"> Explore beneficial uses for produced water, and define water quality for each use. Develop low-cost produced water treatment for beneficial use Develop methods to recover by-products (such as soda ash) that may be of beneficial use. 	<ul style="list-style-type: none"> Technologies that enable produced water to be converted from a problematic waste to a beneficial-use resource may represent considerable savings to the industry while offering economic benefits to the community.

